NEXT MEETING, SEPT. 25th, 1895. PAPER IN THIS ISSUE p. 494.

Entered as matter of the second class at the New York, N. Y. Post Office, November 26th, 1892.

VOLUME XII.
NUMBER 6 & 7.

[COPYRIGHT, 1894.]

JUNE and JULY, 1895.

[DOUBLE NUMBER.]

Annual Subscription $5.00
This Copy - 1.00

TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

CONTENTS.

	PAGE.
Niagara Falls Meeting, June 25th and 26th	331
Properties of Fuse Metals when Subjected to Short Circuits. (Illustrated.) By Walter E. Harrington	332
Theory of the General Alternating Transformer. (Illustrated.) By Charles P. Steinmetz	351
Location of Grounds in Armatures, Fields, Etc. (Illustrated.) By Clarence E. Clifford	366
The Substitution of Electricity for Steam in Railway Practice. By Dr. Louis Duncan	374
Compounding Dynamos for Armature Reaction. (Illustrated.) By Prof. Elihu Thompson	394
Electric Power in Factories and Mills. (Illustrated.) By Dr. F. B. Crocker, V. M. Benedikt and A. F. Ormsbee.	404
Some Features of Alternating Current Systems. (Illustrated.) By Charles P. Steinmetz	432
Some Observations on a Direct Connected 300 K. W. Monocyclic Alternator. (Illustrated.) By Profs. D. C. Jackson and S. B. Fortenbaugh	456
The Cost of Steam Power. II. By Dr. Charles E. Emery	464
Phasing Transformers. (Illustrated.) By Charles S. Bradley, Sept. 25th	494
Report of Prof. R. A. Fessenden	507
Advertisements	509

PUBLISHED MONTHLY BY THE INSTITUTE, UNDER THE SUPERVISION OF THE COMMITTEE ON PAPERS, MEETINGS AND EDITING.

RALPH W. POPE, *Secretary*,
26 CORTLANDT STREET NEW YORK CITY.
Telephone, 2199 Cortlandt.

OFFICERS AND MEMBERS OF THE COUNCIL.

1895-96.

PRESIDENT:
DR. LOUIS DUNCAN,
Term expires 1896.

PAST-PRESIDENTS:

DR. NORVIN GREEN, 1884-5-6.
FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
PROF. ELIHU THOMSON, 1889-90]
PROF. W. A. ANTHONY, 1890-91.
ALEX. GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-93.
DR. EDWIN J. HOUSTON, 1893 4-5.

VICE-PRESIDENTS:

Terms expire 1896.
PROF. WILLIAM A. ANTHONY,
PROF. FRANCIS B. CROCKER,
JAMES HAMBLET.

Terms expire 1897.
ANGUS S. HIBBARD,
DR. MICHAEL I. PUPIN,
W. F. C. HASSON.

MANAGERS:

Terms expire 1896.
PROF. HARRIS J. RYAN,
CHARLES HEWITT
J. J. CARTY,
WILLIAM J. HAMMER.

Terms expire 1897.
A. E. KENNELLY,
WILLIAM D. WEAVER,
CHARLES S. BRADLEY,
W. B. VANSIZE.

Terms expire 1898
CHARLES F. SCOTT,
BION J. ARNOLD,
CARL HERING,
DR. CARY T. HUTCHINSON.

Terms expire 1896.

TREASURER:
GEORGE A. HAMILTON,
22 Thames Street, New York.

SECRETARY:
RALPH W. POPE,
26 Cortlandt St., New York.

Board of Examiners:
E. T. BIRDSALL,
J. STANFORD BROWN.
C. O. MAILLOUX,
EDWARD P. THOMPSON.

Standing Committees appointed by direction of Council:

Committee on Papers, Meetings, and Editing.
FRANCIS B. CROCKER, Chairman.
J. J. CARTY, JOHN W. HOWELL, DR. M. I. PUPIN, GEO. M. PHELPS.
PROF. H. J. RYAN, DR. SCHUYLER S. WHEELER.

Sub-Committee on Editing.
GEORGE A. HAMILTON, Chairman.
C. O. MAILLOUX,
FRANKLIN L. POPE.

Sub-Committee on Papers and Meetings.
T. COMMERFORD MARTIN, Chairman.
HORATIO A. FOSTER,
H. WARD LEONARD,
WM. MAVER, Jr.,
HERBERT LAWS WEBB.

Committee on Finance, Building and Permanent Quarters.
GEORGE M. PHELPS, Chairman.
GEORGE A. HAMILTON, DR. SCHUYLER S. WHEELER, THOMAS A. EDISON,
FRANKLIN L. POPE, FRANCIS R. UPTON, T. COMMERFORD MARTIN,
DR. F. BENEDICT HERZOG.

Library Committee.
J. STANFORD BROWN, Chairman.
GEORGES D'INFREVILLE, GEORGE H. STOCKBRIDGE.

Committee on Units and Standards.
A. E. KENNELLY, Chairman. GEO. A. HAMILTON, DR WM. E. GEYER,
FRANCIS B. CROCKER. WILLIAM D. WEAVER.

Committee on Membership etc.,
RALPH W. POPE, Chairman
THOMAS D. LOCKWOOD, Local Secretary, Boston, Mass.,
DR. LOUIS DUNCAN, " " Baltimore, Md.,
CARL HERING, " " Philadelphia, Pa.,
PROF. EDWARD L. NICHOLS, " Ithaca, N. Y.,
JOSEPH WETZLER, R. N. BAYLIS, H. A. FOSTER, New York City.

BION J. ARNOLD, Local Honorary Secretary.
1541 Marquette Building, Chicago Ill. Telephone, Main 4072.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Twelfth General Meeting.

Niagara Falls, N. Y., June 25, 26, 27 and 28, 1895.

The opening session of the twelfth General Meeting of the Institute was called to order by the Secretary at the Cataract House, Niagara Falls, on Tuesday June 25th, at 10.15 A. M. Two hundred and five members and guests were in attendance.

The Secretary announced that it had been the intention of Past-President Houston to attend the meeting, but he had been unexpectedly detained.

He then introduced the President-elect, Dr. Louis Duncan, of Baltimore, who on taking the Chair was greeted with a hearty round of applause.

President Duncan then introduced Hon. O. W. Cutler, Mayor of Niagara Falls, who addressed the Institute as follows:

Mr. President and Gentlemen of the American Institute of Electrical Engineers:—In behalf of the City of Niagara Falls, I extend to you a hearty and cordial welcome within our gates at this time. We have anticipated your coming with a great deal of pleasure and interest, believing as we do that it is fraught with great benefits to our city. You are doubtless all aware of the progress that has been made in the development of our unrivalled power, and of the proposed transmission and application of it by means of electricity, for which we are so largely indebted to your profession. I venture to say that you will see much in the line of your vocation to interest you while here, in visiting and inspecting our various enterprises, which, as I have already intimated, are of deep interest to the world at large, as well as of great importance to the material interests of our own locality. I trust that your stay here will be as pleasant as it will be interesting.

Again I welcome you and take pleasure in extending to you the freedom of our famous and romantic city. (Applause.)

President Duncan then presented Mr. Walter E. Harrington, of Camden, N. J., who read the following paper:

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 25th, 1895. President Duncan in the Chair.

PROPERTIES OF FUSE METALS WHEN SUBJECTED TO SHORT CIRCUITS.

BY WALTER E. HARRINGTON.

In the TRANSACTIONS of the INSTITUTE, May 1893, page 251 is a paper by Charles P. Matthews, "On the Behavior of Fuse Metals in Direct and Alternate Current Circuits." The paper deals quite exhaustively with the law established by Preece, Prof. Forbes and others, bearing on the relation existing between the diameter of fuse metals and the minimum currents required to fuse the metals, when sufficient time elapses for the fusion to occur.

The law as enunciated is $C = a\, d^{\frac{3}{2}}$ wherein

C = Current in amperes,

d = Diameter of wire in inches,

a = Constant depending on the metal.

The law is not rigorously true but can be depended upon very closely, particularly in the smaller diameters. In the larger diameters the law certainly does not hold true, as has been shown by different observers.

To be true and express the real relation, the constant a should be expressed as a function of d; and as far as my observation has led me, I think a is a linear function of d. It is not the purpose of the writer to elaborate on the various factors entering into the causes underlying the variability of fuse metals. The ground has been pretty thoroughly covered. [1]

1. "Safety fuses versus Magnetic Cut-outs," by W. E. Harrington, *Electrical World*, April 29th, 1893, vol. xxi, No. 17.
Paper read before American Street Railway Association, Milwaukee, October 1893. "Street Car Magnetic Cut-outs," by W. E. Harrington.

On page 261 of Mr. Matthews' paper it is briefly mentioned that fuse metals rarely fuse in practice, under the conditions that the law as obtained demand.

Mr. Preece on short circuit tests made by him writes in a very vague manner covering the results as obtained.

In the course of his professional work the writer has frequently had occasion to desire to know what current would flow through fuse metals on 500-volt short-circuit work. There being absolutely no literature on the subject, and the data to be obtained only by experiment, led to the following series of tests:

The tests were conducted in the power station of the Camden Horse R. R. Co., Camden, N. J., during August, 1894.

The testing room was about 30 feet away from the 'bus bars of the main station switchboard. No. 2 B. and S. gauge copper wires led from the 'bus bars to the testing table. At the switchboard the two leads were connected, one to the ground 'bus bar direct, the other through a 100-ampere knife-blade switch to the trolley side of a Westinghouse magnetic circuit breaker, whose range of adjustment was from 250 amperes to 500 amperes in 50-ampere steps. In the testing room the wires were arranged diagramatically, as show in Fig. 1.

A, was a special fuse block whose terminals were protected by oil, leaving 3″ of fuse in the atmosphere.

B, fuse metal whose fusing current on short-circuit was to be determined.

Paper read before the National Electric Light Association at its 17th Convenvention, Washington, D. C. Feb. 27, 1894. "Faults Incident to the Protection of Lighting and Power Circuits," by L. T. Stanley and W. E. Harrington.

Discussion of Mr. C. P. Matthews' paper "On the Behavior of Fuse Metals in Direct and Alternate Current Circuits." — TRANSACTIONS A. I. E. E., vol. X, page 266.

Catalogue of the Shawmut Fuse Wire Co., 161 High Street, Boston.

"Copper Fuses." Letter by B. S. Lanphear to the *Electrical World*, Jan. 19th, 1895, vol. XXV, No. 3.

Editorial Columns of the *Electrical Engineer*, Sept. 16, 1891, regarding the irreliability of fuses in alternating current work.

Proc. Roy. Soc. Dec. 22, 1887, Article on fusing currents and giving constants for different metals for Law $C = ad^{\frac{3}{2}}$ has the following values:—

Copper	$a = 10244$
Aluminium	$a = 7585$
Platinum	$a = 5172$
German Silver	$a = 5230$
Platinoid	$a = 4750$
Iron	$a = 3148$
Tin	$a = 1462$
Alloy (Tin 1, Lead 2)	$a = 1318$
Lead	$a = 1379$

"Fuse results were determined by using six-inch lengths of wire."

"On the Heating Effects of Electric Currents," by W. H. Preece, *Proc. Roy. Soc.* April 3rd, 1884.

Reports British Association, 1882. Paper by Prof. Forbes.

C, a C-S magnetic circuit breaker carefully calibrated throughout its range, not only for its adjustment, but also as well for 7, 14, 20, 30 and 40-turn coils. A Weston standardized ammeter was employed during calibration. Since the construction of the C-S magnetic circuit breaker is such that the adjustment depends only on weight and distance, the circuit breaker does not vary after use.

D, a 100-ampere knife-blade switch.

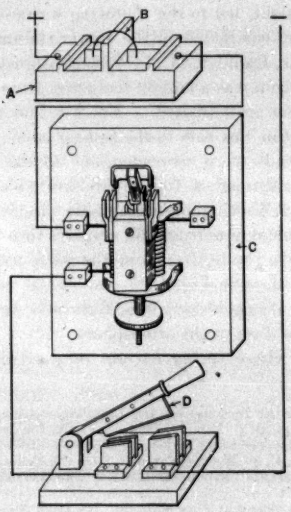


FIG. 1.

The fuse metals tested were placed in fuse block A and switch D thrown. This was repeated with the same size fuse metal a sufficient number of times to find the adjustment of the C-S magnetic circuit breaker which the current flowing would not open, also the adjustment at which the current flowing would open. The current which actually flowed would be somewhere between the two indications as obtained. The accompanying tables give the mean of the two readings. The tests were made during the middle of the day when the loads were light on the power

station. A 200 K.W., G.E. 4-pole, and a 100 K.W.-Edison bipolar generator were running during the obtaining of the following data.

The sizes of fuse wires employed was such that the current flowing through them would not exceed 500 amperes, this being determined by the adjustment of the Westinghouse magnetic circuit breaker referred to before.

In the following tables the first column gives the size of wire in B. & S. gauge; the second column gives the circular mils.

The third column gives the mean of determinations as shown by the indications of the c-s magnetic circuit breaker.

The fourth column gives the constant B entering into the formula $C = B\,d^2$, where

C = current in amperes passing through the fuse metal on a short-circuit.

d = diameter of fuse metal in inches.

B = constant depending on metal and voltage of circuit short-circuit is made on.

The writer noticed that the values as obtained in the tests when compared with the circular mils of the wires tested showed a very close proportionality, showing that the fusing currents on short-circuits followed the law of the square times a constant.

TABLE I.

COPPER.

B. & S. Size Gauge.	d^2 C. M.	S. C. Amps.	B
30	100	37	380,000
29	126	44	350,000
28	159	62	390,000
27	201	80	398,000
26	254	116	456,000
25	320	140	437,000
24	404	225	556,000
23	509	300	589,000
22	642	370	576,000

Table I is for copper. While the constants B vary, especially as the sizes of the wire become larger, this variation is probably due to possible changes of conditions, such as differences of diameter, length of fuse metal, loads on the generators at the time tests were made and heating of the leading wires as the tests were being made. By averaging B the law for copper wires on 500-volt short-circuits could be stated to be:

$$C = 460{,}000\,d^2,$$

or, expressed directly in terms of circular mils, the current which will flow in copper wires on 500-volt short-circuit will be:

$$C = \frac{C.\,M.}{1.9},$$

where C = current in amperes,
$C.\,M.$ = circular mils.

TABLE II.

ALUMINIUM WIRE.

Size B. & S. Gauge.	C. M. d^2.	S. C. Amperes.	B
24	404	200	500,000
21	810	290	358,000
20	1021	325	318,000

For aluminium the law for 500-volt short-circuit currents would be:

$$C = 392{,}000\ d^2.$$

$$C = \frac{C.\,M.}{2.6}.$$

There was one very pronounced peculiarity in the action of aluminium during the short-circuits; the metal seemed to burn longer and pieces of metal would come down after the explosion, still burning.

TABLE III.

STOCK (LEAD AND TIN) FUSE WIRE.

Size B. & S. Gauge.	Rating Fuse Wire Amperes.	C. M. d^2.	S. C. Amperes	B
24	1	404	50	125,000
21	3	810	115	156,000
19	5	1252	130	106,000
17	7	2048	230	118,000
15	10	3256	290	86,000

For fuse metal (ordinary commercial lead and tin alloy) the law for 500-volt short-circuit currents would be:

$$C = 118{,}000\ d^2.$$

$$C = \frac{C.\,M.}{9}.$$

The dense heavy suffocating smoke attending the short-circuiting of lead and tin fuse metals was very pronounced and disagreeable.

Copper gave the best result as regard quantity of current per cross-section of metal. This is shown in the formula for copper

$$C = \frac{C.\,M.}{1.9}.$$

where compared to the other metals the current per circular mil is a maximum, and that the amount of metal to disintegrate for a given current would be a minimum. In all the tests the behavior of the copper short-circuits were noticeably short and attended with a loud explosive report, with but little comparative flash.

One phenomena was noticeable when a cold surface, such as glass, was placed in the immediate path of the discharge; a finely deposited surface of light copper would present itself. This was unquestionably a case of condensation of the copper gases. While it may be argued that the law as enunciated by the writer, covering 500-volt short-circuit currents through fuse metals may not be rigorously true, still it certainly is as true relatively, as that of the law enunciated by Preece, covering the relation between minimum fusing currents and diameters of fuse metals.

In the use of the law for practical work where fuses had to be employed for cases beyond the values as determined by test, the values as obtained by extrapolation in every instance fulfilled the requirements, demonstrating the practical correctness of the law.

A few cases are cited wherein a knowledge of the law would be of practical value. Take railway work, elevator work, in fact, any case of varying power transmission, where if fuse metals are employed, the size of the fuse metal is governed not so much by the normal safe carrying capacity of the apparatus to be protected, as it is by the expected normal jumps of current the apparatus is designed for, and expected at times to carry. The standard 18 to 20-foot street railway equipments consisting of, say, two No. 3 or No. 14 Westinghouse motors, are usually protected by a piece of No. 14 B. & S. gauge copper wire which will normally fuse under a minimum current of approximately 168 amperes—according to Preece's law—whereas under a 500-volt short-circuit, if not prevented by some foreign means, such as feeder magnetic, or generator magnetic circuit breakers, a flow of approximately 2,000 amperes will ensue. Take as another illustration the lead and the tin alloy fuses employed by

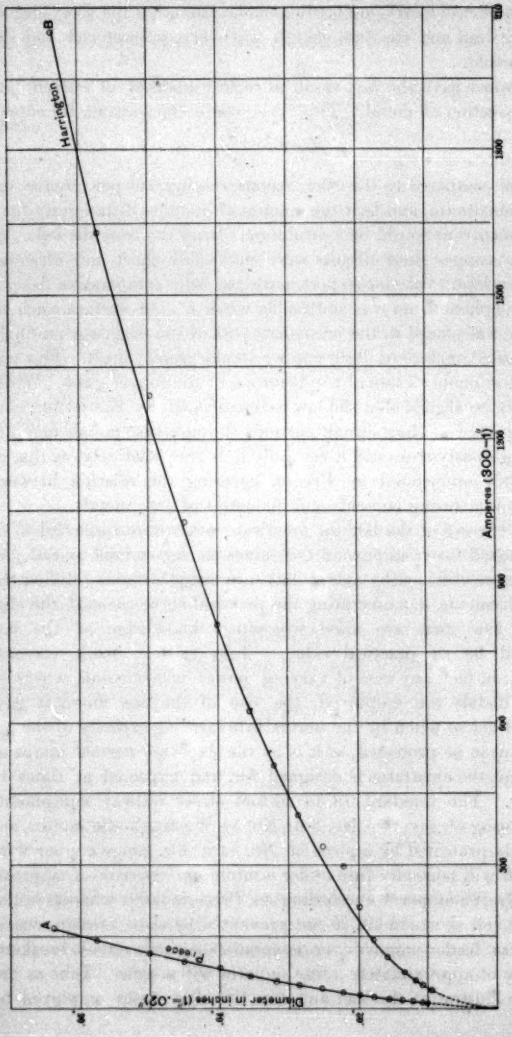

Harrington
B
A
Preece
Diameter in inches (1"=.02")
Amperes (300-1")
1800
1500
1200
900
600
300

FIG. 2.

the General Electric Company for their G. E. 800 equipments and rated to fuse on 100 amperes, will on a 500-volt short-circuit allow a flow of 3600 amperes for approximately .01 of a second, if not prevented by the opening of the power station magnetic circuit breaker. Further, with this latter type of fuse metal, the quantity of metal to disintegrate is so much greater, that usually more harm is done owing to the vicious character of the gas as regards conductivity, this usually establishing other grounds.

TABLE IV.

LAW.

B. & S. Gauge Copper.	Circular Mils.	PREECE.	HARRINGTON.
		Regular Amperes Rating.	Amperes Short Circuit.
30	100.5	11	39
29	126.7	12	44
28	159.7	14½	62
27	201.5	17	80
26	254.0	20	118
25	320.4	24	140
24	404.0	29	215
23	509.4	34	298
22	642.7	41	340
21	810.1	48	4 5
20	1021.5	56	510
19	1252.4	67	625
18	1624.3	82	812
17	2048.2	98	1024
16	2582.9	115	1291
15	3256.7	140	1625
14	4106.8	168	2 53
13	5178.4	195	2589
12	6529.9	235	3264
11	8234.0	280	41 7
10	10381.0	510	5190
9	13094.0	395	6547
8	16509.0	470	8000
7	20816.0	560	100 0
6	26250.0	670	13000
5	33102.0	790	16 00
4	41742.0	950	20000

At this point it is pertinent to refer to a phenomena accompanying the "blowing" of a fuse on a 500-volt short-circuit; that is, the destructive arcing following the disintegration of the fuse, maintained, of course, at the expense of the terminals. In the determination of the law $C = B\,d^2$ the after-arcing, was eliminated by using a protected terminal fuse block.

In a paper entitled "The Destructive Arcing of 500-Volt Fuses" read before the American Street Railway Association at Atlanta, Ga., October, 1894, by the writer, this matter is elaborated upon, and in brief shows that the results due to arcing, following the blowing of a fuse, may under short-circuit conditions

be far worse than even the results attendant upon the passage of such momentarily great currents.

In Table IV, column 1 gives the size in B. & S. gauge of the copper wires; column 2 gives the circular mils; column 3 gives the minimum fusing current as determined by Preece's law, $C = 10244\ d^{\frac{3}{2}}$, and column 4 gives the fusing currents on 500-volt short-circuits as determined by the law, $C = 470{,}000\ d^2$, enunciated by the writer. Fig. 2 graphically illustrates the pronounced disparity of the two laws, showing the curves of currents for diameters: Curve A for Preece's law, and curve B for the law as discovered by the writer. The natural conclusion arising from a knowledge of the above data is that fuse metals are under no circumstances to be considered in the light or nature of a protection.

Discussion.

Dr. Leonard Waldo:—There is one matter that might be commented upon here. Aluminium is coming to play a more and more important part in electrical work, and a word of caution ought to be uttered in regard to the accurate use of the term. If you take a table such as given here, it is of great importance to know just exactly what that aluminium is. Assume that it is commercial aluminium and has a purity of 98 per cent., and that the balance of the ingredients are iron and silicon, which they probably are, and have a resistance about three times as great as that of pure aluminium under the same conditions, while the melting point is only slightly increased. You have, therefore, in questions of fuses, a very marked change in the relations of your aluminium. And aluminium wire that is sold is very often strengthened by the addition of small percentages of copper or nickel, or some of the other metals which are used to give strength to pure aluminium, and those wires pass also in the market under the term "aluminium" wire. I offer this comment as a caution in the use of the term "aluminium," and the use of aluminium wire under such conditions. If Mr. Harrington could furnish an analysis, or in some way define the term "aluminium wire," it would take its place then in terms with copper, which is pretty well understood, and with commercial lead and tin; but even in the case of lead and tin it would be well to indicate the brands, because they vary quite a good deal; and in all questions of resistance, the purity of the metal is of the first consequence.

Mr. Charles P. Steinmetz:—In listening to this paper I must confess that I have not quite understood what the writer intends to prove, and, therefore, I beg to be corrected if I am mistaken in my conclusions. But as I understand it, the writer connected

fuses of various diameters and of various metals into a 500-volt circuit, closed the circuit through the fuses, and observed by means of a magnetic circuit breaker the maximum current which would flow through the fuse at the moment of closure of the circuit, before the fuse is blown.

Assuming even that the magnetic circuit breaker is a suitable means by which to determine instantaneous flow of current—which it is not, because the magnetic circuit breaker is like the fuse, an integrating apparatus, reacting upon the total amount of power passing through, and thus allowing a much larger current to pass for a very short time—assuming even this, then what do we have in reality? We have a 500-volt circuit closed by a fuse, and also by the leads which, compared with the fuse, may or may not be of negligible resistance. In such a circuit, as in any other circuit, the current flowing is equal to the E. M. F. divided by the resistance, and what the writer has observed is merely Ohm's law.

In consequence thereof, if the cross-section of the fuse is half as large, and the leads negligible, the resistance is twice as high, and thus the current half as large, and if a different metal of higher resistance is used, the current will be different also. But the constants derived in this way do not mean anything whatever. If, for instance, the writer had happened to use fuses of twice the length, all the currents, and thus all the constants given in the paper, would have been entirely different. So I do not see how any conclusions can be drawn from this investigation. It merely demonstrates Ohm's law, and that, we all knew before, holds true.

Another incidental remark I may make as to the proposition that a copper fuse is superior to any other fuse. This statement, I think, is based on a misunderstanding of the object of the fuse. A fuse is not in circuit only to open the circuit at a dead short-circuit. It is not even the best means for this. A magnetic circuit breaker, or any other circuit breaker, is far superior to guard against short-circuits, because fuses will not always open on dead short-circuit with unlimited power behind. The object of a fuse is to open the circuit, if the loads exceeds the carrying capacity of the lines, or the rated load. In this case, where the fuse is used in its proper place to guard against excessive load by cutting out the circuit at, say, 50 per cent over-load, the comparison between copper and lead fuses leads to quite different conclusions. Neither of these fuses will blow with such an explosion as on dead short-circuit. Both will be perfectly safe to open the circuit, but as soon as the load approaches fusing point, the copper fuse will be red hot, due to the high melting point of the copper, and thus liable to ignite dust or other combustible material, and set the building on fire. Thus the lead fuse is preferred to the copper fuse, not because it behaves better under a dead short-circuit, but because it opens the circuit and blows a

a temperature below that which will ignite combustible material, and for this reason copper or any other metal with a high melting point is absolutely unsuitable for fuses, except in particular instances where the conditions are such that it can ignite nothing.

DR. F. B. CROCKER:—I had taken somewhat the same view of this subject that Mr. Steinmetz has given, only in a different way. It strikes me, as Mr. Steinmetz says, that this is simply an investigation of the maximum current reached under certain conditions, and it is not exactly what the author intended it to be. Any fuse would carry an infinite current for an infinitesimal period of time, or, to put it a little more practically, it would carry a very great current for a very short time. Now, if the author had closed the circuit for a definite period of time, that might have given certain results. Perhaps the circuit breaker acted in that way and gave a definite time, although, as Mr. Steinmetz says, that would depend on the amount of electrical energy, or the integral of the current which passed.

Furthermore, the question of exactly what a fuse is intended to do is another point to be considered. This "short-circuiting point" is a matter of some practical importance, although I do not think it is the definite and scientific quantity that is implied in the paper, because we want to protect coils of wire on dynamos or other apparatus from the effects of short-circuiting under certain conditions. If the fuse does not blow—and presumably the fuse is of lower current capacity than the wire of the machine to be protected—then it stands to reason that the wire will not be injured. Therefore, after all, in a practical common sense way, perhaps this test is a useful and important one. And often this is the object of the fuse after all.

But looking at the matter as a physical problem, it seems to me the questions involved are these:—that a fuse has a definite capacity for heat, and requires a certain number of calories to raise it to its fusing point; that amount being the product of its weight, specific heat and the temperature of fusion. That is the amount of heat required to raise it to fusing point, assuming that the action is so rapid that no heat is lost, which I think would be approximately true in this case. It is practically instantaneous, and the loss, I think, would be almost negligible. Now, a certain amount of electrical energy is required to produce that amount of heat, and that amount of electrical energy is just as definite as anything can possibly be. It is simply the electrical equivalent of that amount of thermal energy. We have a certain E. M. F. and a certain impedance to overcome, due to the resistance and the self-induction, and a certain time during which that current flows. Consequently, as a physical problem, we can investigate it by calculation. We can tell beforehand what current and what time would be required.

MR. C. J. REED:—It seems to me that from a physical standpoint I cannot agree with Dr. Crocker that it simply depends on

a certain amount of heat generated, but the element of time and the surrounding conditions have all to do with it. The question as to whether the fuse will melt or not, appear to depend on whether there is a generation of heat in the wire at a rate exceeding that at which it is dissipated. If so, the temperature will continue to increase until the melting point is reached. If the conditions are such that with any given current, whether great or small, the heat is dissipated more rapidly than it is produced in the wire, then it will never reach fusion. It will reach a certain temperature and will not go beyond that. On the other hand, it is perfectly evident that if there is no opportunity for energy to dissipate, even an infinitesimal current would in the course of time fuse the largest wire. That seems to me very evident. If no heat can escape, even an infinitesimal current, theoretically, would in time heat the wire to its melting point; and, therefore, it seems to me that the only way any formula could be applied, would be under conditions in which the radiation must be absolutely the same for all temperatures of the wire, and in which no heat could escape through the terminals. That limits us practically to considering the central portion of a very long fuse, and one situated in a vacuum, or under other conditions, where the temperature of the surrounding space could be kept perfectly uniform. Then, as the temperature of the fuse rises, the difference between its temperature and that of the surrounding medium could be determined for any given temperature. But under ordinary conditions the most uniform that I can conceive of would be that of an exposure to air of uniform temperature. But this is impossible to get. If we compare, for instance, a fuse wire of very small diameter, say .001 inch, and another of a diameter of one inch, the small wire heating to its melting point, say for instance 2,000 or 1,500 degrees, if it is a wire that melts at that temperature, will heat only a very small amount of the surrounding air, whereas a wire one inch in diameter would heat a considerable thickness of the surrounding air, and consequently reduce its rate of cooling much more than a small wire would. It seems to me, then, that any formula we can get will be valueless unless we take into consideration the surrounding conditions.

So far as the comparison of copper wire and lead wire fuses is concerned, I cannot entirely agree with Mr. Steinmetz. I remember in the early days of electric lighting, when I did not know any better, I put up a lant in which I used copper wire fuses for electric lights on a 100-volt circuit. I used a No. 36 copper wire fuse about two inches long on every lamp. Later, when we got the Edison lead wire fuses in their cut-out boxes, I always noticed that the copper wire fuses when they went out never made any fuss, not the slightest noise of any kind, and only a very minute spark; while the lead wire fuses would invariably make a loud report and send a lot of melted metal around, which was likely to do damage; and I came to the conclusion that for

this particular service the best kind of a fuse is one which will give the least amount of melted metal, and not the one that melts at the lowest temperature. It does not matter whether the metal melts at a low temperature or not, as the arc is very sure to heat it up to about the same temperature. Hence, the more metal the more danger.

PROF. W. A. ANTHONY:—There was one point in this paper that I did not fully understand. If I understood correctly, these experiments were all made with the same circuit connection, the same connection from the switch-board, and with the magnetic circuit breaker in circuit; and if I understood correctly, the experiments were made some 30 feet or so distant from the switch-board, and therefore leads of that length were necessary in order to reach the fuse. Now, under such circumstances, I can hardly see how the resistance of the connections could be negligible in comparison with the fuse. It would seem to me that the connections under such circumstances would be quite large, that the fuse would not be a large percentage of the whole resistance, and, therefore, that the amount of current that would flow would depend perhaps as much upon the connections, instruments, contacts, etc., in circuit, as upon the fuse itself, and that if these experiments were to be made with entirely different connections, with larger or shorter wires, that entirely different results would be reached, that a larger current would flow through the same fuse, because the amount of current that flows in this case, as Mr. Steinmetz says, is determined by Ohm's law; that is, by Ohm's law excepting the self-induction or impedance that comes in. And if we had a less resistance as a whole, no matter whether the fuse itself were of less resistance or not, then a much larger current would have passed through the same fuse. Now, unless the conditions were such that the connections were extremely small in comparison with the fuses, I cannot see why the result should not be as I have stated, and cannot see that the results given really show us anything of importance.

PROF. ELIHU THOMSON:—It seems to me that the question under discussion resolves itself into a question of what is the proper function of a fuse, whether it is to save the apparatus from an overload, or whether it is to save it only in the case of a short-circuit. It is conceivable that if the fuse is not to give any relief to an overload of say 50 per cent, but is merely to be active on short-circuit, then the copper fuse might perhaps be the best. But if the fuse is to act on, say, 50 per cent. overload, or some definite proportion of the normal load, then it strikes me that tin, lead, or fusible metal is undoubtedly the best, because we must not neglect the economy of the fuse. If, for example, we use a copper wire for a fuse, we must make it longer than the fuse metal in order that the heat of the fuse will not be conducted back to the terminals. Copper being such an excellent conductor of heat, it will, of course, if made short, deliver its heat rapidly

to the terminals, and to get rid of any effect on the terminals, we would have to enlarge or lengthen out the copper. At the same time, if we lengthen it out and run it on a normal load at a considerable elevation of temperature so that it may fuse on, say, 50 per cent. overload, then we are wasting energy. We will have a great number of fuses which are running hot, and we know that a small wire, if of some length, can get rid of a considerable amount of energy. Again, with the tin and lead fuse, the conductivity for heat is low and the fuse runs at comparatively near normal temperature unless the overload comes. At that time it is ready to melt at a moderate elevation of temperature. If the function of the fuse is to save the apparatus in case of overload, then a soft metal must undoubtedly be the best.

Now what is the function of the fuse in the railway motor? Certainly not to save the apparatus in a case of short-circuit, because you cannot have a true short-circuit. You have a drop in the trolley line, you have a drop in the returns, and you have all through the connection a drop which, of course, would limit the current and remove any liability of any such values being reached as are stated in the paper. If the current did reach those high values for an instant, there would not necessarily be any bad result to follow, if the instant after, say .1 second or .01 second, all things are righted. Then it does not matter if we have just that momentary high flux of current. Now the fact is, that a car may be upon a grade, and for some reason or other it may be slipping down the grade. The motorman puts on the current rather briskly, and he may get for the moment 150 to 200 amperes. I have known that to occur. I have been on cars when tests were made, when the motors took that current for a time, when rotating slightly in the opposite direction current was suddenly put on. The fuse, which might have blown at, say, 50 or 60 amperes, did not, of course, blow under the conditions, but if the conditions had existed for any considerable time, the fuse would have blown and saved the apparatus. In other words, the motor could stand a high value of current for a short time without sustaining any harm. It seems to me that the practical question is the one which you have to consider in this connection.

MR. GEO. W. BLODGETT:—I take it the object of an investigation of this sort is one of two, either to establish a law, or to furnish a practical application. It seems to me that no formula can be devised in which a single constant would embrace all the conditions which are to be met, because, as has been said, the length of the fuse and the duration of time are both factors which determine to a degree the point at which it will melt. Perhaps I have overlooked it, but I see nowhere stated the length of the fuse which Mr. Harrington employed. Nor does he state definitely the time which elapsed between the closing of the circuit and the blowing of the fuse. Perhaps he does that in one or two cases, though I did not have an opportunity to read the

paper beforehand. I think the experiment, to be complete, should state exactly the length of fuse employed and the time during which it was in circuit. A formula to be applicable to all cases should bring in those two factors, and it is rigidly true only when the exact conditions under which the test was made are reproduced. But we never have in practice exactly the conditions which we impose in the laboratory for an experiment of this sort, and if the object is to determine a law under theoretical conditions, then it should be distinctly stated what the conditions were, under which the test was made. But if it is to furnish a practical application, then as nearly as possible the conditions which exist in average practice should be reproduced, and it should be definitely stated what the conditions are under which the practical application is made in the test. I am sorry that Mr. Harrington did not state the length of the fuses and the composition of the alloys which he used, because varying the proportions of lead and tin, for instance, in the fuse which he employed, would vary quite considerably the melting point of the fuses. Some experiments made by the American Bell Telephone Company I believe developed this fact, that a current which was perfectly harmless for a short time, if continued through the coils of a telephone bell, for instance, for a considerable time, would destroy it. Therefore they found it necessary to provide against what they called "sneak" currents, that is, currents which for a short time will do no damage, but which continued a long time will do harm by a gradual rise of temperature, because, owing to the density and the number of turns in the coil of wire, the energy can not be dissipated as fast as it is communicated to the coil, and, therefore, a dangerous temperature results; and that should be taken into account in the application of a fuse to a particular purpose, how long the current can be continued without injury to the apparatus.

Mr. Allan V. Garratt:—What I was about to say was precisely what Prof. Thomson has said, and he has said it so much better than I could, that I will not go over the same ground. But I wish to say just this one thing more. It seems to me the most criticisable point of the whole paper is contained in the very last sentence, which I will read. "The natural conclusion arising "from a knowledge of the above data is that fuse metals are under "no circumstances to be considered in the light or nature of a pro-"tection." That is not a conservative statement. If the words "under no circumstances" were changed to "under some circumstances," it certainly would meet the approval of us all. There is probably not a man here who has not many times in his own experience seen fuse metals do precisely what they were intended to do. The point, I think, that is brought out in this discussion by Dr. Crocker, that we must first make up our own mind what we want fuse wire to do before we can find fault with it, is a very important one. We know in every machine designed

what the bare wire will carry, and we are familiar with what will happen in the machine if an excessive current passes through it; and the machines are so designed that under the service for which they are intended they will dissipate the heat as fast as they are likely to get it under commercial conditions, and under most abnormal conditions the fuse acts.

Hence, although there is a great deal of value in this paper, yet its conclusion, I think, is erroneous, and not perhaps of the practical utility that its author intended.

MR. HARRINGTON:—As to the matter of the length of fuse, I think I mentioned in the paper its being three inches long, and the time of opening the circuit in these instances approximated .01 second. As to the use of fuses in railway work, where the fuse is intended to carry current for the jumps, and where you are liable to have the current as tabulated under short-circuit column on account of low line resistance, I think the law true in the majority of instances. It is a very noticeable fact in connection with railway work, that in climbing grades fuses very frequently blow when they are least wanted to blow; and yet if you put in a fuse large enough to carry the currents for that service, on a "ground" or "short-circuit," the current, while it may not rise to the quantity tabulated, still it will rise to such quantity as will by the torque or shock produced, cause a great deal of damage, which the protection of a circuit breaker will unquestionably prevent, as practice has proved.

That the use of fuses as a means of protection is not satisfactory is demonstrated by the use of magnetic circuit breakers on the Metropolitan railway in Chicago, and other large railways.

As to the conclusion concerning the non-protection that fuses afford, it is the occasional arising of this phenomenon that leads to their not being depended upon. For instance, very recently at the Broad Street station of the Pennsylvania Railroad, in Philadelphia, having Westinghouse generators, and using very large fuses, a short-circuit took place. The fuse did not blow. The generator was very badly injured and the crank-shaft broken, and considerable damage occurred. In the report that the engineers made, they recommended the use of magnetic circuit breakers, although before that time the same engineers had never considered circuit breakers as being advisable. It is the liability of these things to happen, owing to the properties that fuses have, that seems to point to their lack of reliability.

In the matter of the refinement of the law as enunciated, while it might have been conducted on a finer basis and results obtained which would be rigorously true, yet knowing that such a condition would not be attained, I was very careful to state all the facts as far as I was able to obtain them, aiming to bring out prominently the point that fuses have properties which have very seldom, if ever heretofore, been noticed and provided for. It has been my effort simply to bring these phenomena before you.

MR. REED:—I would like to ask the gentleman if I understood correctly that the time in these experiments was .01 second.

MR. HARRINGTON:—Approximately that.

MR. REED:—In all cases?

MR. HARRINGTON:—Approximately that, yes; very closely

MR. REED:—In that case it does not seem to me, then, that this formula could be expected to apply in any way, because this is a formula which is intended to show the relation between the diameter of the fuse metals and the minimum currents required to fuse the metals when sufficient time elapses for fusion to occur. Now it is very evident that if you take two fuses of different diameters, under different conditions, and of the same metal, and if your current is just sufficient under those conditions to fuse the wire, it will not generally fuse both of them in the same time, being of different diameters; and hence to expect that they would all fuse in .01 second would be expecting something that certainly could not take place.

MR. HARRINGTON:—You are probably thinking about the law enunciated by Preece, where sufficient time elapses for fusion to occur. That law is: $C = a\,d^{\frac{3}{2}}$.

MR. REED:—Any time which you are going to allow for a given current to fuse the metals will not be the same for the fusion of different diameters, even of the same metal. The time will be such as is required for the increase of temperature to come up to the fusing point. You must remember that energy is being dissipated all the time and being developed all the time. The time when the fusing temperature will be reached will depend upon how much faster energy is being developed than it is being dissipated.

MR. HARRINGTON:—That is true, but in the law, as shown by Preece, time is eliminated. In fact, time drops out of the question when developed, and since time is ignored there, the actual conditions obtained in the tests were such that I have ignored the time. But I happen to know from other tests that it was about .01 second.

MR. STEINMETZ:—I wish to refer to what I believe is a misunderstanding of a statement made by Professor Crocker. Professor Crocker stated that the blowing of a fuse was merely a question of calories. Obviously that means the calories accumulated in the fuse, and this is the calories impressed upon it, in case of an excessive current, where the fusing takes place so quickly as to allow no time for noticeable radiation. Otherwise it is the difference between the calories impressed and the calories radiated by the fuse.

Now, with regard to the formula given in the paper, we can draw conclusions from the numerical values which plainly show their fallacy. It is stated there that the fuse in the Westinghouse car equipment allows 2,000 amperes to flow, and in the General Electric Co.'s equipment 3,600 amperes on a short-

circuit. Now that means that at 500 volts impressed and by series parallel control, with the two motors of the car in series, the resistance of each Westinghouse motor is $\frac{250}{1000}$, or $\frac{1}{4}$ of an ohm, and the resistance of a General Electric Co.'s motor only $\frac{1}{15}$ of an ohm. Although both companies claim that their motors are very efficient, I do not think that either of them makes any claim to such low resistance as that.

MR. CARL HERING, Philadelphia:—In connection with the subject of fuse wires, a specimen which I have here may be of interest. It is a portion of the fuse wire of the high-tension, overhead lines of the famous Lauffen-Frankfort transmission plant, and was handed to me just now by Dr. Lobach, one of the engineers of that plant, and which he now presents to the INSTITUTE. It is a copper wire 0.1 mm. in diameter. The fuses were two metres long, stretched overhead between two poles, and consisted of two of these wires in multiple in each of the circuits of that three-phase system. 200 H. P. at about 20,000 volts were transmitted through these fuses. It will be remembered that the center point of this three-wire system was grounded, and that these fuses acted as a cut-out to kill the line in case one of the three wires became grounded; an official test demonstrating their efficacy in a satisfactory manner was made before the plant was allowed to be operated.

MR. BLODGETT:—The shape of the fuse has also an important bearing on the temperature at which it will melt. If it is in the form of a flat strip, it will carry a higher current than if it is in the form of a solid rod or circular wire, particularly if it be intended to carry a large current. I saw an illustration of the conditions existing very nicely shown by the Electric Forging Company, in some experiments with their apparatus, in which an iron rod about one inch in diameter was heated to a bright red heat, and by regulating the current carefully it could be maintained at a constant temperature. That temperature was brought so high that while the outside of the rod was in a stable condition, owing to the dissipation of the energy into the surrounding air, the interior was melted, and would after a little time find for itself a vent through the outside shell, and the interior of the rod which was then fluid would run out, leaving a tube, while the outside would remain at a temperature sufficient to preserve its shape and integrity, showing that the dissipation of the energy under such conditions bears an important relation to the temperature at which destruction will occur. So in a large fuse, we should get a decidedly greater carrying capacity in the shape of a flat thin strip than we would if it were a solid circular or rectangular section.

CAPT. WM. BROPHY:—Nearly every point in this paper has been covered and discussed, except the concluding paragraph. I must say that I am nearly in accord with the writer in what he there says. I would simply amend it in this way: "The natural

conclusion arising from a knowledge of the above data is that fuse metals are under *most* circumstances," etc. It has been my province to deal with fuse metals for the last twelve years. The functions which are required are prevention of an abnormal flow of current over the wires, thereby increasing their temperature to a dangerous point. I have only very recently tested commercial fuses—sent out and bought them—and I find that none of them come anywhere near doing what they are advertised to do. The current that they carry varies from 50 per cent. to 250 per cent. above what they are marked. Many of them have the same property as copper wire,—they heat; and I have maintained them in a red hot condition for five or ten minutes, or longer, if I so desire. I would like to see something substituted for the present commercial fuse, for a great many reasons. The men in charge of plants are apt to use fuse metals that are entirely too large, even if they did what they are supposed to do, protect the wires in which they are inserted. As they age, I find that their carrying capacity increases very rapidly. In fact, there are innumerable objections that could be stated to the use of fuse metal for the protection of wires and prevention of overheating the same, if time permitted.

Mr. Charles P. Steinmetz then read the following paper:

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25th, 1895. President Duncan in the Chair.

THEORY OF THE GENERAL ALTERNATING CURRENT TRANSFORMER.

BY CHARLES P. STEINMETZ.

The simplest alternating current apparatus is the alternating current transformer. It consists of a magnetic circuit, interlinked with two electric circuits or sets of electric circuits. The one, the primary circuit, is excited by an impressed E. M. F., while in the other, the secondary circuit, an E. M. F. is induced. Thus, in the primary circuit, power is consumed, in the secondary circuit a corresponding amount of power is produced, or in other words, power is transferred through space, from primary to secondary circuit. This transfer of power finds its mechanical equivalent in a repulsive thrust acting between primary and secondary. Thus, if the secondary coil is not held rigidly as in the stationary transformer, it will be repelled and move away from the primary. This mechanical effect is made use of in the induction motor, which represents a transformer whose secondary is mounted movably with regard to the primary in such a way that, while set in rotation, it still remains in the primary field of force.

We see thus that the stationary transformer and the induction motor are merely different applications of the same apparatus, comprising a magnetic circuit interlinked with two electric circuits. Such an apparatus can properly be called a "*general alternating current transformer*," and its equations in complex quantities are given in the following:—

The equations of the stationary transformer and those of the induction motor are merely specializations of the general alternating current transformer equations.

The general alternating current transformer transforms between electrical and mechanical power, and changes not only E. M. F.'s and currents, but frequencies also.

Besides the magnetic flux interlinked with both primary and secondary electric circuit, a magnetic cross flux passes in the transformer between primary and secondary, surrounding one coil only, without being interlinked with the other. This magnetic cross flux is proportional to the current flowing in the electric circuit, and constitutes what is called the self induction of the transformer. As seen, as self-induction of a transformer circuit, not the total flux produced by and interlinked with this circuit is understood, but only that—usually small—part of the flux which surrounds the one circuit without interlinking with the other, and is thus produced by the M. M. F. of one circuit only.

The common magnetic flux of the transformer is produced by the resultant M. M. F. of both electric circuits. It is determined by the counter E. M. F., the number of turns, and the frequency of the electric circuit, by the equation:

$$E = \sqrt{2}\,\pi\, N\, n\, M\, 10^{-8}.$$

Where E = effective E. M. F.
N = frequency.
n = number of turns.
M = maximum magnetic flux

The M. M. F. producing this flux, or the resultant M. M. F. of primary and secondary circuit, is determined by shape and magnetic characteristic of the material composing the magnetic circuit, and by the magnetic induction. At open secondary circuit, this M. M. F. is the M. M. F. of the primary current, which in this case is called the exciting current, and consists of an energy component, the magnetic energy current, and a reactive component, the magnetizing current.

In the general alternating current transformer, where the secondary is movable with regard to the primary, the rate of cutting of the secondary electric circuit with the mutual magnetic flux is different from that of the primary. Thus, the frequencies of both circuits are different, and the induced E. M. F.'s are not proportional to the number of turns as in the stationary transformer, but to the product of number of turns into frequency.

Let, in a general alternating current transformer:

$$k = \text{ratio } \frac{\text{secondary}}{\text{primary}} \text{ frequency, or "slip,"}$$

thus, if:

N = primary frequency, or frequency of impressed E. M. F.,

$$k\,N = \text{secondary frequency},$$

and the E. M. F. induced per secondary turn by the mutual flux has to the E. M. F. induced per primary turn the ratio k,

$k = 0$ represents synchronous motion of the secondary,

$k < 0$ represents motion above synchronism—driven by external mechanical power, as will be seen,

$k = 1$ represents standstill,

$k > 1$ represents backward motion of the secondary, that is, motion against the mechanical force acting between primary and secondary (thus representing driving by external mechanical power).

Let:

n_0 = number of primary turns in series per circuit,

n_1 = number of secondary turns in series per circuit,

$a = \frac{n_0}{n_1}$ = ratio of turns,

$Y_0 = \rho_0 + j\,\sigma_0$ = primary admittance, per circuit, where

ρ_0 = effective conductance,

σ_0 = susceptance,

$U_0 = r_0 - j\,s_0$ = internal primary impedance per circuit, where

r_0 = effective resistance of primary circuit,

s_0 = reactance of primary circuit,

$U_{11} = r_1 - j\,s_1$ = internal secondary impedance per circuit at standstill, or for $k = 1$, where

r_1 = effective resistance of secondary coil,

s_1 = reactance of secondary coil at standstill, or full frequency: $k = 1$.

Since the reactance is proportional to the frequency, at the slip k, or the secondary frequency $k\,N$, the secondary impedance is:

$$U_1 = r_1 - j\,k\,s_1.$$

Let the secondary circuit be closed by an external resistance r, and an external reactance, and denote the latter by s at fre-

quency N, then at frequency $k\,N$, or slip k, it will be $= k\,s$, and thus:

$$U = r - j\,k\,s = \text{external secondary impedance.}^{1}$$

Let:

E_0 = primary impressed E. M. F. per circuit.

E_0' = E. M. F. consumed by primary counter E. M. F.

E_1 = secondary terminal E. M. F.

E_1' = secondary induced E. M. F.

e = E. M. F. induced per turn by the mutual magnetic flux, at full frequency N.

C_0 = primary current.

C_{00} = primary exciting current.

C_1 = secondary current.

It is then:

Secondary induced E. M. F.:

$$E_1' = k\,n_1\,e.$$

Total secondary impedance:

$$U_1 + U = (r_1 + r) - j\,k\,(s_1 + s);$$

hence, secondary current:

$$C_1 = \frac{E_1'}{U_1 + U} = \frac{k\,n_1\,e}{(r_1 + r) - j\,k\,(s_1 + s)}.$$

Secondary terminal voltage:

$$E_1 = E_1' - C_1\,U_1 = C_1\,U$$

$$= k\,n_1\,e\left\{1 - \frac{r_1 - j\,k\,s_1}{(r_1 + r) - j\,k\,(s_1 + s)}\right\} = \frac{k\,n_1\,e\,(r - j\,k\,s)}{(r_1 + r) - j\,k\,s_1 + s)}.$$

E. M. F. consumed by primary counter E. M. F.:

$$E_0' = -\,n_0\,e;$$

hence, primary exciting current:

$$C_{00} = E_0'\,Y_0 = -\,n_0\,e\,(\rho_0 + j\,\sigma_0).$$

---

1 This applies to the case, where the secondary contains inductive reactance only, or rather that kind of reactance, which is proportional to the frequency. In a condenser, the reactance is inversely proportional to the frequency, in a synchronous motor under circumstances independent of the frequency. Thus in general we have to set: $s = s' + s'' + s'''$, where s' is that part of the reactance, which is proportional to the frequency, s'' that part of the reactance independent of the frequency, and s''' that part of the reactance, which is inversely proportional to the frequency, and have thus, at slip k, or frequency $k\,N$, the external secondary reactance: $k\,s' + s'' + \frac{s'''}{k}$.

Component of primary current corresponding to secondary current C_1:

$$C_1' = -\frac{C_1}{a}$$

$$= -\frac{n_0 k e}{a^2 \{(r_1 + r) - j k (s_1 + s)\}};$$

hence, total primary current:

$$C_0 = C_{00} + C_1'$$

$$= -k n_0 e \left\{\frac{1}{a_2} \frac{1}{(r_1 + r) - j k (s_1 + s)} + \frac{\rho_0 + j k \sigma_0}{k}\right\}.$$

Primary impressed E. M. F.:

$$E_0 = E_0' + C_0 U_0$$

$$= -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{(r_1 + r) - j k (s_1 + s)} + (r_0 - j s_0)(\rho_0 + j \sigma_0)\right\}$$

We get thus, as the

Equations of the General Alternating Current Transformer,

of ratio of turns: a, and ratio of frequencies: k, with the E. M. F. induced per turn at full frequency: e, as parameter, the values:

Primary impressed E. M. F.:

$$E_0 = -n_0 e \left\{1 + \frac{k}{a^2} \frac{r_0 - j s_0}{(r_1 + r) - j k (s_1 + s)} + (r_0 - j s_0)(\rho_0 + j \sigma_0)\right\}.$$

Secondary terminal voltage:

$$E_1 = k n_1 e \left\{1 - \frac{r_1 - j k s_1}{(r_1 + r) - j k (s_1 + s)}\right\} = k n_1 e \frac{r - j k s}{(r_1 + r) - j k (s_1 + s)}.$$

Primary current:

$$C_0 = -k n_0 e \left\{\frac{1}{a^2} \frac{1}{(r_1 + r) - j k (s_1 + s)} + \frac{\rho_0 + j k \sigma_0}{k}\right\}.$$

Secondary current:

$$C_1 = \frac{k n_1 e}{(r_1 + r) - j k (s_1 + s)}.$$

Therefrom we get:

Ratio of currents:

$$\frac{C_0}{C_1} = -\frac{1}{a} \left\{1 + \frac{a^2}{k} (\rho_0 + j \sigma_0) [(r_1 + r) - j (s_1 + s)]\right\}.$$

Ratio of E. M. F.'s:

$$\frac{E_0}{E_1} = -\frac{a}{k}\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)-j\,k\,(s_1+s)} + (r_0 - j\,s_0)\,(\rho_0 + j\,\sigma_0)}{1 - \frac{r_1 - j\,k\,s_1}{(r_1+r)-j\,k\,(s_1+s)}}\right\}$$

Total apparent primary impedance:

$$U_t = \frac{E_0}{C_0} = \frac{a^2}{k}\,\{(r_1+r) - j\,(s_1+s)\}$$

$$\left\{\frac{1+\frac{k}{a^2}\frac{r_0 - j\,s_0}{(r_1+r)+j\,k\,(s_1+s)} + (r_0 - j\,s_0)\;(\rho_0 + j\,\sigma_0}{1+\frac{a^2}{k}\,(\rho_0 + j\,\sigma_0)\;[(r_1+r) - j\,k\,(s_1+s)]}\right\}$$

Where:

$$s = s' + \frac{s''}{k} + \frac{s'''}{k^2}$$

in the general secondary circuit as discussed in foot note, page 4.

Substituting in these equations:

$$k = 1,$$

gives the

General Equations of the Stationary Alternating Current Transformer:

$$E_0 = -\,n_0\,e\,\{1 + \frac{1}{a^2}\,\frac{U_0}{U_1+U} + U_0\,Y_0\}.$$

$$E_1 = n_1\,e\,\{1 - \frac{U_1}{U_1+U}\} = n_1\,e\,\frac{U}{U_1+U}.$$

$$C_0 = -\,n_0\,e\,\left\{\frac{1}{a^2\,(U_1+U)} + Y_0\right\}.$$

$$C_1 = \frac{n_1\,e}{U_1+U}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\,\left\{1 + a^2\,Y_0\,(U_1+U)\right\}.$$

$$\frac{E_0}{E_1} = -\,a\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1-\frac{U_1}{U_1+U}}\right\}$$

$$U_t = \frac{E_0}{C_0} = a^2\,(U_1+U)\,\left\{\frac{1+\frac{U_0}{a^2\,(U_1+U)} + U_0\,Y_0}{1+a^2\,Y_0\,(U_1+U)}\right\}$$

Substituting in the equations of the general alternating current transformer:

$$U = 0,$$

gives the

General Equations of the Induction Motor:

$$E_0 = -n_0 e \left\{1 + \frac{k}{a^2}\frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 + j s_0)(\rho_0 + j \sigma_0)\right\}.$$

$$E_1 = 0.$$

$$C_0 = -k n_0 e \left\{\frac{1}{a^2 (r_1 - j k s_1)} + \frac{\rho_0 + j \sigma_0}{k}\right\}$$

$$C_1 = \frac{k n_1 e}{r_1 - j k \sigma_1}.$$

$$\frac{C_0}{C_1} = -\frac{1}{a}\left\{1 + \frac{a^2}{k}(\rho_0 + j \sigma_0)(r_1 - j k s_1)\right\}.$$

$$U_1 = \frac{a^2}{k}(r_1 - j k s_1)\left\{\frac{1 + \frac{k}{a^2}\frac{r_0 - j s_0}{r_1 - j k s_1} + (r_0 - j s_0)(\rho_0 + j \sigma_0}{1 + \frac{a^2}{k}(r_1 - j k s_1)(\rho_0 + j \sigma_0)}\right\}$$

Returning now to the general alternating current transformer, we have by substituting:

$$(r_1 + r)^2 + k^2 (s_1 + s)^2 = u_k^2,$$

and separating the real and imaginary quantities:

$$E_0 = -n_0 e \left\{\left[1 + \frac{k}{a^2 u_k^2}\Big(r_0 (r_1 + r) + k s_0 (s_1 + s)\Big) + (r_0 \rho_0 + s_0 \sigma_0)\right] + j\left[\frac{k}{a^2 u_k^2}\Big(k r_0 (s_1 + s) - s_0 (r_1 + r)\Big) + (r_0 \sigma_0 - s_0 \rho_0)\right]\right\}.$$

$$C_0 = -k n_0 e \left\{\left[\frac{r_1 + r}{a^2 u_k^2} + \frac{\rho_0}{k}\right] + j\left[\frac{k (s_1 + s)}{a^2 u_k^2} + \frac{\sigma_0}{k}\right]\right\}.$$

$$C_1 = \frac{k n_1 e}{u_k^2}\Big\{(r_1 + r) + j k (s_1 + s)\Big\}.$$

Neglecting the exciting current, or rather considering it as a separate and independent shunt circuit outside of the transformer, as can approximately be done, and assuming the primary

impedance reduced to the secondary circuit as equal to the secondary impedance:

$$Y_0 = 0,$$
$$\frac{U_0}{a^2} = U_{11}.$$

Substituting this in the equations of the general transformer, we get:

$$E_0 = -n_0 e \left\{1 + \frac{k}{u_k^2}\left[r_1(r_1+r) + k s_1(s_1+s)\right] + \frac{j k}{u_k^2}\left[k r_1(s_1+s) - s_1(r_1+r)\right]\right\}.$$

$$E_1 = \frac{k n_1 e}{u_k^2}\left\{\left[r(r_1+r) + k^2 s(s_1+s)\right] + jk\left[r s_1 - s r_1\right]\right\}$$

$$C_0 = -\frac{k n_1 e}{a u_k^2}\left\{(r_1+r) j k (s_1+s)\right\}.$$

$$C_1 = \frac{k n_1 e}{u_k^2}\left\{(r_1+r) j k (s_1+s)\right\}.$$

If:

$E = a + j b$ = E. M. F., in complex quantities, and

$C = c + j d$ = current, in complex quantities,

the power is:

$$P = |E, C| = E C \cos(E, C) = a c + b d.$$

Making use of this, and denoting:

$$\frac{k n_1^2 e^2}{u_k^2} = w$$

gives:

Secondary output of the transformer:

$$W_1 = |E_1, C_1| = \left(\frac{k n_1 e}{u_k}\right)^2 r = k r w.$$

Internal loss in secondary circuit:

$$W_1^1 = c_1^2 r_1 = \left(\frac{k n_1 e}{u_k}\right)^2 r_1 = k r_1 w.$$

Total secondary power:

$$W_1 + W_1^1 = \left(\frac{k n_1 e}{u_k}\right)^2 (r + r_1) = k w (r + r_1).$$

Internal loss in primary circuit:

$$W_0^1 = c_0^2 r_1 = \left(\frac{k n_1 e}{u_k}\right)^2 r_1 = k^2 r_1 w.$$

Total electrical output plus loss:

$$W^1 = W_1 + W_1^1 + W_0^1 = \left(\frac{k\, n_1\, e}{u_k}\right)^2 (r + 2\, r_1) = k\, w\, (r + 2\, r_1).$$

Total electrical input of primary:

$$W_0 = |\, E_0,\ C_0\, | = k \left(\frac{n_1\, e}{u_k}\right)^2 (r + r_1 + k\, r_1) = w\, (r + r_1 + k\, r_1).$$

Hence, mechanical output of transformer:

$$W = W_0 - W^1 = w\, (1 - k)\, (r + r_1).$$

$$\text{Ratio: } \frac{\text{mechanical output}}{\text{total secondary power}} = \frac{W}{W_1 + W_1^1} = \frac{1 - k}{k} = \frac{\text{speed}}{\text{slip}}.$$

Thus:

In a general alternating transformer of ratio of turns a, and ratio of frequencies k, neglecting exciting current, it is:

Electrical input in primary:

$$W_0 = \frac{k\, n_1^2\, e^2\, (r + r_1 + k\, r_1)}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Mechanical output:

$$W = \frac{k\, (1 - k)\, n_1^2\, e^2\, (r + r_1)}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Electrical output of secondary:

$$W_1 = \frac{k^2\, n_1^2\, e^2\, r}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Losses in transformer:

$$W_0^1 + W_1^1 = W^1 = \frac{1\, k^2\, n_1^2\, e^2\, r_1}{(r_1 + r)^2 + k^2\, (s_1 + s)^2}.$$

Of these quantities, W^1 and W_1 are always positive; W_0 and W can be positive or negative, according to the value of k. Thus the apparatus can either produce mechanical power, acting as a motor, or consume mechanical power, and it can either consume electrical power or produce electrical power, as a generator.

At:

$k = 0$, synchronism, $W_0 = 0$, $W = 0$, $W_1 = 0$.

At:

$0 < k < 1$, between synchronism and standstill.

W_1, W and W_0 are positive, that is, the apparatus consumes electrical power W_0 in the primary, and produces mechanical power W and electrical power $W_1 + W_1^1$ in the secondary, which

is partly— W_1^1—consumed by the internal secondary resistance, partly— W_1—available at the secondary terminals.

In this case it is: $$\frac{W_1 + W_1^1}{W} = \frac{k}{1-k},$$

That is, of the electrical power consumed in the primary circuit — W_0—a part W_0^1 is consumed by the internal primary resistance, the remainder transmitted to the secondary, and divides between electrical power $W_1 + W_1^1$ and mechanical power W in the proportion of the slip, or drop below synchronism—k—, to the speed: $1 - k$.

In this range, the apparatus is a motor.

At: $$k > 1,$$ or backwards driving,

$W < 0$, or negative, that is, the apparatus requires mechanical power for driving.

It is then: $$W_0 - W_0^1 - W_1^1 < W_1,$$

that is: the secondary electrical power is produced partly by the primary electrical power, partly by the mechanical power, and the apparatus acts simultaneously as transformer and as alternating current generator, with the secondary as armature.

The ratio of mechanical input to electrical input is the ratio of speed to synchronism.

In this case, the secondary frequency is higher than the primary.

At: $K < 0$, beyond synchronism.

$W < 0$, that is, the apparatus has to be driven by mechanical power.

$W_0 < 0$, that is, the primary circuit produces electrical power, from the mechanical input.

At: $$r + r_1 + k\,r_1 = 0, \qquad \text{or:} \qquad k < -\frac{r + r_1}{r},$$

the electrical power produced in the primary becomes less than required to cover the losses of power, and W_0 becomes positive again.

We have thus; $$k < -\frac{r + r_1}{r},$$

consumes mechanical and primary electric power; produces secondary electric power.

$$-\frac{r + r_1}{r} < k < 0,$$

consumes mechanical, and produces electrical power in primary and in secondary circuit.

$$0 < k < 1,$$

consumes primary electric power, and produces mechanical and secondary electrical power.

$$1 < k,$$

consumes mechanical and primary electrical power; produces secondary electrical power.

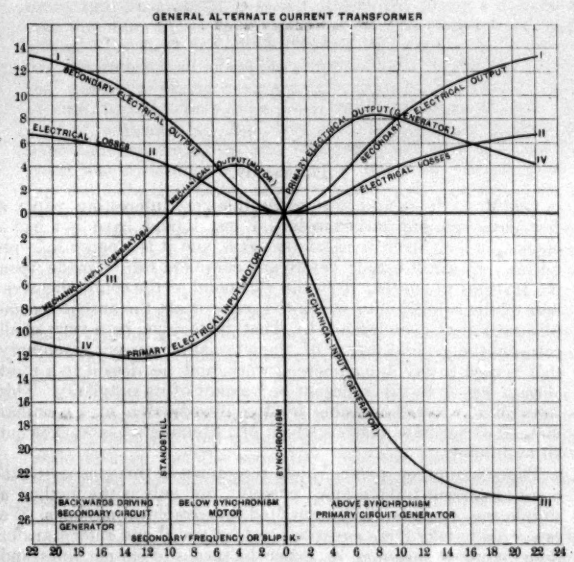


FIG. 1.

As an instance, in Fig. 1 are plotted, with the slip k as abscissae, the values of:

secondary electrical output	as curve I,
total internal loss	as curve II,
mechanical output	as curve III,
primary electrical input	as curve IV,

for the values:

$$n_1 e = 100,$$
$$r_1 = .1,$$
$$s_1 = .2,$$
$$r = .4,$$
$$s = .3;$$

hence:

$$W_1 = \frac{16{,}000\ k^2}{1 + k^2},$$

$$W_0^1 + W_1^1 = \frac{8{,}000\ k^2}{1 + k^2},$$

$$W_0 = \frac{4{,}000\ k + (5 + k)}{1 + k^2},$$

$$W = \frac{20{,}000\ k\ (1 - k)}{1 + k^2}.$$

Discussion.

Dr. M. I. Pupin:—I was given this very interesting paper a few days ago, but unfortunately I lost it and have not had a chance to look over it carefully again, and it is a paper that requires very careful study before any comment can be made upon it. It seems to me that from the viewpoint of the comprehensiveness of the subject with which the paper deals, the author accomplishes just what he intended. That is, to give in a very small compass the general theory of the alternating current machinery that is used to-day in commercial work, and he does it in a most elegant way. But it is elegant on account of its simplicity. This simplicity is made possible by the introduction of a peculiar method of accurate analysis which Mr. Steinmetz has worked out all by himself.

There is another point which recommends this general treatment of current transformers, namely: not only is the method a simple one, but it is easily translated into graphical methods. We can actually take these equations and by pencil and ruler transfer their physical meaning to paper by means of simple lines and curves.

I saw a machine at the Frankfort Exhibition, which, if I remember correctly, was constructed by Schückert. It would give you an alternating current, a two-phase direct current, a three-phase current, or anything else you wished, and for that reason it was called the "maid-of-all-work." This theory of alternating current machinery which Mr. Steinmetz has given us may be called the "maid-of-all-work" in alternating current machinery, because it gives information not only about the alternating current transformer, but also about the alternating current generator and alternating current induction

motor. Perhaps Mr. Steinmetz will some day construct a machine which can be used at the same time as an alternating current generator, an induction motor, transformer, or anything else that occasion may demand. It is a very original and very interesting piece of work that he has presented in this paper.

There is one thing though that Mr. Steinmetz has not mentioned, and that is that it is an ideal theory. I mention this because some time ago I had the pleasure of presenting somebody else's paper before this INSTITUTE. Having been called upon to present the paper, I studied it carefully, and fell in love with it more or less, and I feel that way still. But Mr. Steinmetz was there, and he thought because I praised the paper, he ought to take the other side, so as to make the evening pleasant and interesting. The fault he had to find with the paper was that it was too theoretical, and it was too mathematical. [Laughter.] But that was not anything so very serious from an engineering point of view, because there are a great many engineers who are very fond of mathematics. But there was a more serious defect in the paper still, according to Mr. Steinmetz, and that was that the paper was misleading because it gave theoretical results concerning the induction motor, which results were deduced from an hypothesis which never occurs in practice, and that is that there was no magnetic leakage; and if there was any, that this magnetic leakage was not affected by the load. Now I have the same fault to find with Mr. Steinmetz's paper. That is, that he has not taken into account the magnetic leakage. He could not do that, of course, because that is impossible, but he has not stated that he has not taken account of the magnetic leakage; and therefore I think that in that respect the paper is somewhat misleading.

MR. STEINMETZ:—Coming to the last point first, I think Dr. Pupin has misunderstood me. The magnetic leakage is considered in the paper, and very completely. Not only the primary magnetic leakage, but the secondary magnetic leakage also. It is what I call and introduce here as the magnetic cross flux, that is that magnetic flux produced by one circuit and interlinked with this circuit only, but not interlinked with the other circuit. Its coefficients are denoted here by "s" and "s_1," primary internal reactance, and secondary internal reactance. This magnetic leakage is proportional to the current because reactance is of the nature of a resistance, and is treated as such in my paper. The only error which can come in here is the lack of proportionality between the magnetic cross flux and the current producing it, that is, the variation of the ohmic reactance. However, this magnetic leakage is a cross flux in a circuit consisting partly of air, while the magnetic induction in the iron part of the circuit is far below saturation, and in such a circuit, theoretically as well as experimentally, the magnetic flux is always found very strictly proportional to the current, or in other words, the reactance is constant.

Coming back now to the other proposition made by Dr. Pupin, to devise a "maid-of-all-work," a motor which does everything, I have such a machine in operation in our factory, and have used it quite extensively for experimental work for about a year and a half. It was originally built as an experimental induction motor, and after completing experiments with it, it is now used according to circumstances, either as a transformer or a frequencncy changer, or an induction motor to produce mechanical power, or as a generator to get currents of a frequency which I cannot get directly in another way, say 250 cycles per second, or to transform from three-phase to single-phase, or from single-phase to three-phase, etc. I shall be glad to show the apparatus to anyone of the gentlemen present, who visits Schenectady.

DR. PUPIN:—I observed of course s and s_1 and I know perfectly well what Mr. Steinmetz meant to convey by these quantities, but at the same time I do not agree with him that the geometrical factor is independent of the load, because there is a great deal of shifting of the magnetic circuits—what we call distortion. Now as to the second point, I am glad to hear that there is a machine of the kind described. I wish that we had one, so that I could show to students in one machine, the whole theory and practice of alternating currents: and I think that if that machine is not too expensive I should order one. If the General Electric Company really has that machine, I should then propose, in deference to that fact, that the title of the paper be "The Theory of the General Electric Alternating Current Transformer."

PROF. JOHN E. DAVIES:—The remarkable feature of this paper, it seems to me, is its generalization, if I understand it correctly, of the notion of difference of phase and its changes. We have been so accustomed to regard difference of phase as more or less constant, and as included within the ordinary limits of 90 or of 180 degrees, that at first thought it seems to be somewhat difficult to enlarge our conceptions in this regard. That is to say, in the notion of slip, and in the use of the constant k to indicate it, it seems to me that Mr. Steinmetz has introduced here an exceedingly important idea, together with an appropriate notation for it. I do not know but that this idea of slip may be already perfectly familiar to the majority of electrical engineers here present, but it has not been familiar to me as an instructor in electricity and magnetism. I have been, of course, entirely familiar with the transformation of voltage and the transformation of current in the static transformer; but the transformation of periodicity and the use of a special constant in the formulæ to represent it, I must confess, struck me as a very novel, and at the same time as an extremely important modification of the usual treatment of the alternating current transformer. We can readily understand mere difference of phase when it amounts to one, two, or more periods, in advance or in retardation; but we have here an actual transformation of periodicity due to motion of the secondary, and

it strikes me that that portion of the paper is an extremely original and valuable one both from a purely theoretical and practical standpoint.

MR. CLARENCE E. GIFFORD, of Jamestown, N. Y., then read the following paper:

A paper presented at the Twelfth Genera Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25th, 1895. President Duncan in the Cha.r.

LOCATION OF GROUNDS IN ARMATURES, FIELDS, ETC.

BY CLARENCE E. GIFFORD.

This paper presents no novel scientific principles. The methods herein described are but simple adaptations of the principle of the Wheatstone bridge. They have been in use by the writer for several years, and he, having devised them for his own use, and found them very rapid, accurate and simple, is led to believe that they may be of considerable service to others. *The Electrical World* "digest" of March 16th notices a slightly similar, but evidently less perfect method, published by Mr. Bronsson in the London *Electrical Review*. The insufficiency of Mr. Bronsson's method in cases where two grounds, at some distance apart exist, is admitted. The methods herein described deal successfully with such cases.

If the work can be performed in a very quiet room, two or three cells of battery, a telephone receiver and connecting wires, comprise the necessary apparatus. In some cases two "table binding posts" and a foot or two of No. 18 or No. 20 bright iron wire will be a convenient addition. Where noise will not permit the use of a telephone, a dead-beat reflecting galvanometer, a milli-voltmeter, or some other form of delicate and rapid working visual indicator must be used instead. If an armature is to be tested without removing it from the machine; connection with the battery may be made through the brushes, first making certain that the short-circuiting switch is opened, if dealing with an arc machine. The points of connection with the battery need not be diametrically opposite, and may be made by the wires

being firmly pressed against the commutator by an assistant, if more convenient.

Good electrical contact between metallic surfaces can better be secured by cleaning the same thoroughly with kerosene, which removes foreign matter, and is so fluid that it will in no way interfere with perfect contact, when moderate pressure is applied. Especially when making measurements of resistance of armature sections, it is even advisable to have the surface of the commutator quite wet with kerosene during the operation, as this avoids trouble from grease or dirt which might get on the surface from handling, subsequent to cleaning, and it also prevents the contact points becoming oxidized by any sparks which may occur at the moment of breaking contact. True, the oil is an insulator, but we use it in this case as a detergent simply.

Returning to the armature; connection being made between battery and commutator, first determine whether the armature circuit is complete throughout. If the circuit is complete, a click will be heard in the telephone when the two terminals of the same are brought in contact with any two contiguous bars of the commutator, or when contact is broken. If an open circuit exists on either side of the circuit, of course no sound will be heard in the telephone when used on that side, except when connection is made or broken by it between the bars lying on opposite sides of the break. See Fig. 1.

Close any open circuit temporarily by bridging between the two bars with a drop of solder. Two or more breaks can evidently be located by suitably shifting the battery contacts and searching as before. Open circuits will, of course, when an armature continues in work, soon cause burns between the bars that will indicate unmistakably their location. Having closed any open circuits, and the battery being connected to two points of the commutator, approximately opposite each other, one terminal of the telephone is connected to the armature shaft, or frame of the machine, and the other terminal is drawn completely around over the surface of the commutator, while the telephone is held to the ear. If only one ground exists, two balancing points, or points giving the least noise in the telephone will be found.

In an armature of ordinary construction, one of the points so found will be on the bar nearest the real ground, while the other balancing point bears what might be termed a "bridge relation"

to the first, being at practically the same potential; the armature itself forming in reality a veritable Wheatstone bridge.

Now, shift the points of battery contact a few bars either way and the true ground, if but one exists, will be indicated in precisely the same position as before, while the other balancing point will shift every time the battery contacts are shifted. See Fig. 2.

If two grounds exist, two balancing points will be found, as before, but both points will shift more or less when the battery contacts are shifted, provided the grounds lie on opposite sides of the same battery contact. This case will be considered later.

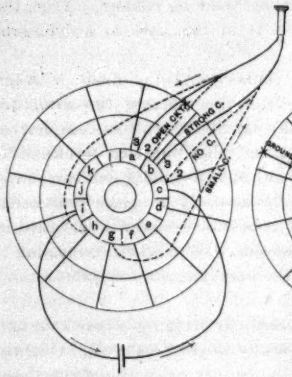


FIG. 1

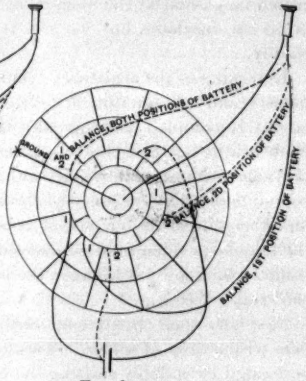


FIG. 2

In the case of one ground, having determined its location approximately, fix it as closely as may be by making and breaking contact with the telephone terminal on each of the more quiet bars, separately, until by comparison, the two giving the faintest clicks are determined. If your hearing has served you correctly these two bars lie nearest the trouble, the fainter one being the nearer. Prove the non-existence of a second ground by placing one of the battery contacts on the first bar to the right of the apparently permanent balancing point just found, and then on the first bar to the left of said point, the other contact being nearly diametrically opposite. This balancing point should still remain unchanged if no other ground exists.

The next step is to connect the battery to these two bars just fixed upon as lying nearest the trouble. The armature still forms a "bridge," the portion included between the two contiguous bars to which the battery is now connected forming the one side, and the remainder of the armature, the other side. See Fig. 3.

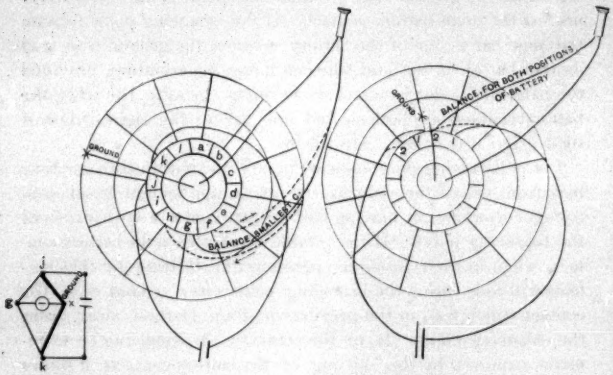
One of the telephone terminals is now connected to the shaft as before, and the other terminal again drawn around the commutator. If the balancing point is found, say one-sixth to one-half, the long way around from one battery contact to the other, (these contacts being on two contiguous bars) the trouble lies in the coil between those two bars, and the point of trouble divides the coil in the same ratio as the balancing point divides the remainder of the armature, the ground and the balancing point being respectively nearest the same battery contact. If the balancing point falls on the same bar as one of the battery contacts, the ground is located on that bar or on the lead between it and the armature, provided the balancing point is found to be upon the same bar when the battery contacts are both shifted one bar to the right or left of their original position. See Fig. 4.

If the balancing point appears to be found within three or four bars from one of the contacts, the precaution should be taken to test its correctness by moving both battery contacts one bar toward the balancing point. If the trouble was between the battery contacts when in their previous position, this shifting of the contacts will now throw the balancing point clear around onto the contact which was, in the previous position farthest away from the balancing point. If, on the contrary, the balancing point remains unmoved by this shifting of the battery contacts, it shows that this balancing point is the point nearest the real ground, and that the ear was deceived in its first supposed approximation, which, with due care, however, is not likely to occur.

If such error has been made, the new point, as indicated, together with first the bar on one side of it, and then on the other, must be tried as points of battery contact; or, much better, make a new start with the contacts nearly at opposite sides of the commutator and proceed as before. A single 20,000 ohm ground on a one ohm armature should be located accurately in not over three minutes, in a quiet room. Higher resistance grounds require more battery and more care. Armatures of very low resistance also offer greater difficulty.

Where two grounds are found to exist, as indicated by the change of location of both balancing points, under the conditions

before stated, when the battery contacts are shifted, the following mode of procedure will answer the purpose well, and is simple. Fix the battery contacts at any two points of the commutator nearly opposite each other, preferably at points to be determined by trial, that will cause the balancing points to fall nearly diametrically opposite to each other, and determine and mark the two balancing points, as then shown. Now place the battery contacts on the balancing points just found. If only one ground exists, the two balancing points and one battery contact will all be coincident in one point. If two grounds exist, both balancing points will be shifted from their former position. Open the arm-



[Analogue to Fig. 3.]

FIG. 3. FIG. 4.

ature circuit by unsoldering one of the ends of a coil connecting with the lead of the bar that is marked in the first part of this test, as one of the balancing points. Place one of the battery contacts on the armature shaft, and the other on the marked balancing point that is farthest from the point where the circuit has been opened. Next place one telephone terminal on the first bar to the right of the opened wire, and draw the other terminal from the same point, toward the right, over the surface of the commutator. The telephone will be absolutely silent until the moving terminal has just passed the ground nearest to it, and strikes the first bar beyond the same, when it will click. This

ground lies in the coil between this first bar giving a click and the one passed just previously, or else in the said previous bar.

The other ground is obviously to be located in a similar manner, by placing one telephone terminal on the bar just to the left of the open wire, and from that point searching toward the left with the other terminal. Only in cases where one ground is of very low, and one of very high resistance will any difficulty be experienced in locating both accurately before either is removed.

The coils thus indicated may have their terminals unsoldered, when it can be readily ascertained with each, whether the ground be in the coil or in the bar just preceding it.

If scientifically inclined, or if otherwise preferable, the circuit may be opened at a point somewhere midway between the two indicated coils instead of disconnecting those coils, and the exact location of each ground determined as follows: Take a piece of "broom wire" about 18 inches long, new and clean, screw the ends firmly into two clean, brass table binding posts, and into the other holes of the same posts, screw the battery terminals. Have an assistant press the corners of the bases of the binding posts into very firm contact with the two bars that lie at the ends of the indicated coil, observing the directions previously given for securing clean contact. Place one telephone terminal in contact with the shaft, and with the other find the balancing point on the wire. This point will indicate the relative position of the ground in the coil, or commutator bar, as the case may be. If more than two grounds were suspected, the two lying the farthest apart would be approximately located by the first part of the two-ground process, and if these coils were not disconnected before proceeding farther, it would be well to make two openings in the circuit, close to and lying between these outer grounds, then locate definitely these two extreme grounds, and proceed with the remaining section somewhat as with a complete armature, except that you would commence by connecting the battery to the terminals of this section, and would then bridge the telephone from the shaft to the different portions of the section, and would complete the process by applying the remainder of the two-ground test.

In dealing with a cross-connected Gramme ring, an obvious change would be made in the points of application of the battery; and as many points of apparent trouble would be indicated as there were series of cross-connections.

After location of these points it would be necessary to use the auxiliary wire loop, as before described, between these points, to determine which is nearest the trouble. This fact being determined, it would in case of a single ground (indicated by the permanency of the balancing point) become necessary to remove the cross-connections from two bars before proceeding farther. The auxiliary wire loop would properly be used to complete the process.

The ordinary "closed coil" ring or drum armatures are types to which these methods are directly applicable.

The sections of open coil armatures would receive the same treatment as field coils.

Familiarity with any special forms of armature will doubtless suggest to the ingenious mind, modifications of these methods suited to those forms, but it would be improper to attempt here to deal with specialties whose names are legion.

Where wet grounds exist it will always be better, when practicable, to dry them out before making the final test, as certain sections may show faults which will not be permanent. Wet grounds will of course give a click in the telephone when bridged from the commutator to the shaft when no battery is attached, owing to galvanic action of the water on the copper winding and the iron core.

Whenever necessary to deal with wet grounds in testing, it is better to make at least four tests, reversing the battery after each test, and taking the mean of the four determinations.

Field coils, also any wires of uniform cross-section, the extremities of which are accessible and within a reasonable distance of each other, can of course be easily tested for grounds by soldering or firmly clamping a bare wire of suitable size between the extremities of the conductor to be tested, applying a battery to the junctions, and bridging with a telephone between the bare wire and the object upon which the conductor is grounded. This will give only the location of a single ground, or the "resultant" of two grounds. A "T.-H." rheostat should have the battery connected to the two extremities, and the point of apparent ground determined by bridging with a telephone between the frame and the several contact plates. Then apply the battery to the frame and point of apparent ground, connect one terminal of the telephone with each extremity successively, and search from it toward the center

with the other terminal, as in the case of searching for two grounds in an armature.

In determining the location of grounds that are of very low resistance, a good induction coil similiar to that used in the Blake transmitter may be used with advantage in connection with the telephone receiver. The receiver is placed in circuit with the secondary of the coil, and the "bridging" is done with the primary. With high resistance grounds the best results are obtained by using the receiver only.

After the reading of Mr. Gifford's paper, a recess was taken until 8 P. M.

The afternoon was devoted to an inspection of the power house of the Niagara Falls Power Company, the electric plants of the Pittsburg Reduction Company, and of the Niagara Falls and Buffalo Electric Light and Power Company, and the mill of the Niagara Falls Paper Company.

The evening session was called to order at 8.20 P. M. by Vice-President Wm. A. Anthony, when the following inaugural address was delivered by President Louis Duncan:

Inaugural address of the President before the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 25, 1895. Vice-President Anthony in the Chair.

THE SUBSTITUTION OF ELECTRICITY FOR STEAM IN RAILWAY PRACTICE.

BY LOUIS DUNCAN.

In an address delivered before this Institute in June, 1892, Mr. Frank J. Sprague spoke of the coming development of electricity as applied to railways, and outlined his views as to the direction of this development. In the last three years great extensions have been made in electrical transportation, and it seems well to review briefly the amount of these extensions and their direction. In this paper I shall consider electric traction as it stands at present and not the possibilities of the future.

In the last seven years electricity has largely taken the place of horses for tramway work, and it is now beginning to replace cables, although the latter have been recently installed at great expense. At first the lines were confined to the limits of towns and cities, but they have been extended first into the suburbs, and then to neighboring towns, and the extensions have brought them in competition with the steam roads. The reports of the earnings of the railroad companies in the United States show that after paying fixed charges only a small amount of the net profit remains to be applied to dividends on the stock. Any general decrease in the earnings, even if it is only a small percentage of the total amount, will wipe out the narrow margin that is now applied to dividends, and the absorption by the electrical lines of the local travel formerly conducted by the steam lines promises to do this. At first the managers of the larger steam roads ignored the growth of their electrical rivals, but the time has come when they can no longer ignore the decrease in the

receipts from their local passenger travel, and they are beginning to face the difficulty and to carefully study the situation.

In this paper I will briefly take up the following questions:

1. Given a railroad system at present operated by steam; will it pay to change entirely to electricity, or to make a partial substitution, and how should the change be made?

2. If entirely new lines are to be built, is it likely that it will pay to equip them electrically, and how should they be equipped?

3. I will describe the equipment of the Baltimore and Ohio tunnel plant and draw from it what morals I can.

In order that it should pay a railroad to make a change in its motive power, the effect of the change must be either to increase the receipts or decrease the expenses by an amount equal to the interest on the first cost of the change. That is, there should theoretically be such a gain; practically, the amount should be greater in order to justify the change, to take into account those elements not capable of exact calculation, and also the fact that an increase in the fixed charges of a road is a more serious matter than the mere amount of it, for although the average for a number of years might show a gain by the substitution of electricity in a bad year the increased fixed charge might cause difficulty.

There are two very distinct sides to the question of transportation, the passenger side and the freight side, and their requirements for good service are very different.

First, taking up the question of passenger travel. The receipts of a road are increased by running trains at short intervals and at high speeds, and this is a condition peculiarly favorable to electricity. On an electric line, short trains equally distributed over the track give a greater station efficiency, and the lowest cost of equipment of both station and line. The cost of train service is somewhat greater, but is compensated by the saving in the other items.

The cost of hauling a given number of passengers between given points by steam is greatly increased when the number of trains is increased. The efficiency is less, and the cost of equipment and of train service is greater. Wellington states that doubling the number of engines for a given traffic increases the cost of transportation about 50 per cent.

On the other hand, if we take up the question of freight traffic, the conditions of greatest economy are reached when trains of a maximum weight are hauled by a single locomotive. The

tendency in late years has been in the direction of increasing the size of the locomotive, the capacity of the cars and the length of the trains. These changes have necessitated more solid and expensive road beds, heavier rails and general strengthening of bridges. The outlay has been enormous, but the decreased cost per ton mile for freight transportation has shown the wisdom of the change. On one of the larger roads which publishes careful yearly statistics, I find that the cost of transportation per ton mile in 1870 was 1.15 cent, and in 1890 .56 cent; on another road it was 1.9 cent in 1864 and .447 cent in 1893. The number of tons per train mile on the first road in 1870 was 103, while in 1890 it was 226. In attempting to carry on traffic of this kind by electrical locomotives operated from a central station, we find that we are at a great disadvantage because of the irregular service necessitated by the freight traffic and the unequal distribution of the load along the line. Suppose, for instance, that there were two stations supplying the line and that the traffic was uniformly distributed along it, then the capacity of each station would be one-half of the total required capacity. Suppose, however, that the entire traffic was concentrated in one train, then each station would have to have a capacity equal to the total power required for hauling the entire traffic, as the train would be first supplied from one station, and then from the other. The line also would have to have a capacity suitable for handling the total traffic. If a number of heavy trains were used, and the traffic was irregular and liable to be congested at one point, as in the case of freight service, then again the capacity of the stations would have to be greater than that required to supply one-half of the normal traffic. If we were to decide to transmit the current to a longer distance and to supply all the track from one station, using transformer devices along the line, then the capacity of the station itself would only be that required for the normal traffic of the line, but the transformer devices would have to be sufficient to handle the maximum traffic of the section which they supplied, and would have to be given a capacity greatly in excess of their average load in order to supply this energy. We must distinctly bear in mind in considering the application of electricity to steam roads, that any departure from a uniform distribution of load along the line will increase both the cost of equipment and the cost of operation.

In looking over the reports of the same road from which I

have given freight statistics, I find that in 1870 the receipts per passenger mile were 2.09 cents, while the expenses were 1.59 cents. In 1890 the receipts were 1.9 cent, while the expenses were 1.47 cent. During this period the passengers per train mile have decreased from 79 to 59. Comparing these figures with those given for freight transportation, we find that the two types of traffic have gone in opposite directions in the period we have been considering. The amount of freight transported per train mile has more than doubled, and the expense has decreased more than one-half. The passengers per train mile, on the other hand, have decreased, and the expenses have changed only a slight amount, notwithstanding the greater economies that have been put in force in the interval. Passenger traffic has come in the direction in which electricity is the most economical for transportation; freight traffic, on the other hand, has gone in the direction where electricity becomes most costly. It might be argued that some new scheme for freight transportation by electricity might be used, but it would be difficult to devise any system more economical than that at present in use, and the great amount of through traffic on freight lines precludes the possibility of devising any system which differs radically from that at present in use. For instance, taking the figures from the records of the Pennsylvania Railroad for 1893, I find that the freight mileage of foreign cars on the lines of the Pennsylvania road east of Pittsburg is in round numbers, 370,000,000, while the freight mileage of home cars is 436,000,000, making almost 46 per cent. of the total mileage made by foreign cars. It would seem, then, impossible to change the present system of freight traffic without disorganizing the service and decreasing the freight revenue of the road. The importance of freight traffic is shown by the fact that the earnings from freight on all the roads in the United States is between two and one-half and three times as great as that for passenger traffic. The New York Central Railroad Company in 1892 received from their freight traffic $26,000,000, and from their passenger traffic $13,000,000. On the lines of the Pennsylvania Railroad east of Pittsburg the freight receipts were $47,000,000 as against $17,000,000 for passenger receipts.

Suppose, then, the question comes up before the managers of a road as to whether they are to equip their lines to be operated entirely by electricity. It seems to me as matters now stand it

will not pay trunk lines to change the method of operation for freight traffic, and the question to be considered would be the operating of the lines partly by steam and partly by electricity. Let us consider if it is possible to run the passenger service wholly or partly by electricity. Considering a two track road doing a through as well as a local business, I think we can decide that, unless the case be an exceptional one, it will not pay to equip the main line electrically. It is necessary that the through express service be continued and that the freight service be continued, and an attempt to operate the local trains with the through trains could not be successful if there was any considerable amount of through traffic. With a four-track road the condition of affairs is somewhat different. If the road operates between cities acting as terminal points for all passenger traffic, as with some of the lines between Boston and New York, then by equipping all four tracks it would be possible to run express service at short intervals on two of the tracks, and on the other two tracks to run freight and local trains. At present it would not pay to use electric locomotives operated from a central station for the freight service, but the local service could be operated electrically; and as the speed of the local trains would be approximately equal to that of the freight, there need be no serious interference with the traffic. We would then have express passenger service working under favorable conditions—that is, with a number of trains evenly distributed, a local service operated under similar favorable conditions and with no interruption to the freight traffic. If the road, however, is to transport a considerable number of foreign cars as, for example, the New York Central or the Pennsylvania railroad, then the condition of affairs for express service would not be so favorable, and the question of the equipment of the tracks for express service would have to be carefully considered. As far as the branch lines go, whether it would pay to partially or wholly substitute electricity for steam depends upon the local conditions. A long branch with a small amount of local traffic it would not pay to equip, but on a short branch with considerable passenger traffic and comparatively little freight traffic such equipment would pay. I find that in 1892 the total number of through passengers carried by the New York Central road was 234,650, while the number of local passengers was 21,978,979. It will be seen that the through traffic is but a small percentage of the total number of passengers,

and that the question of preserving the local traffic is of great importance. Now the greater part of this local traffic will, in the next few years, be taken by the electric roads paralleling the steam road, unless some effort is made either to control the electric roads or to give an equally good service between adjacent towns. This latter is possible, using the ordinary steam tracks, only when the distances between towns are small, and the amount of freight or through traffic is also small.

There are certain kinds of local traffic which the steam roads must, to a large extent, lose, and which in the nature of things they cannot regain. In large cities having a considerable suburban traffic the trolley roads, forming as they do a network of lines within the city and extending in every direction into the suburbs, offer advantages with which the steam roads cannot compete. In Philadelphia one of the large steam lines lost so much traffic that it has attempted to regain it by reducing prices and increasing the number of trains. In this effort it has partly succeeded, but at the cost of greater expense and decreased receipts. To counterbalance this loss at central points railroads may hope, by the introduction of electricity, to increase their earnings along the lines and on their branches.

As to the nature of the equipment that will be required, it would depend on the work to be done and the branch that is to be equipped. In some cases it might be well to use single electric cars running on the steam tracks between towns, and on the local tram lines in the towns. As the speed would be very different in the town and on the railroad line, and as the voltage could also be different, it would be well in this case to use a number of motors on the car, and to use a series parallel controller, the motors being in series for the town traffic. For instance, suppose we wish to run at a maximum speed of 40 miles per hour between two towns, and it is economical to use 1,000 volts on the line, we could use two motors on the car, run them in parallel on the main line at a speed of 40 miles per hour, while in town, with a voltage of 500. we could run them in series at a speed of 10 miles per hour. I can hardly imagine a case where the three-wire system could be economically used for such service on the steam lines.

The condition of affairs in electric transportation is at present curious. The trolley companies, by extending their lines, are working from tramway transportation to through transportation.

They are attacking the problem by development from small motors to larger ones. The railroad companies starting with the large units are coming down in the direction of the present trolley systems, as in the case of the Nantasket Beach road of the New York, New Haven & Hartford company. Perhaps in the future they will meet, and some standard electrical system will be adopted for the present steam road. I think then, that in the case taken up, the policy of the road will be to equip those branches for which the conditions are favorable, with a trolley, run comparatively large motor cars capable of drawing one or two ordinary passenger or freight cars as trailers, using the present steam service for their freight traffic when necessary. This will allow the necessary through travel, will give the required local service between towns, and will not interfere with the freight traffic.

As for the systems to be used for such services, I believe that at the present moment the continuous current overhead trolley system is the only one that can be selected with a certainty of successful operation. It gives a minimum complication in the way of conveying the current to the cars, it allows a considerable range of speed with a comparatively high efficiency, and our experience with it is such that successful operation could be at once guaranteed. By using different voltages in the towns and on the line, both high and low speeds can be obtained. If the line to be operated is to be very long, it might be best to use rotary transformers at different sub-stations along it, the line being supplied by continuous currents from the sub-stations. In fact, the three systems that are at present possible are: First, the ordinary direct current system; second, a system in which direct currents are used on the line and rotary transformers supplied by alternating currents are placed along it, and third, a two or three-phase system supplying rotary field motors on the cars. In the latter case it would be well to employ different periods in the towns and on the lines.

The second case which I wish to consider, is that of roads built for an entirely new electrical equipment such, for instance, as the elevated roads in Chicago and the underground rapid transit road in New York, or the proposed Washington-Baltim re Boulevard line. In most of these cases the traffic is almost entirely a passenger traffic, and the conditions are especially favorable for the operation of electricity. Taking, first, the case of

the New York underground road, there will probably be required about 150 trains for local service, each train having five ordinary cars and a motor car. For the express service there would be about 25 trains of, say, four ordinary cars with a motor car. For this it would probably be best to use the direct current three-wire system, one of the cars on the train being equipped with motors and acting as a locomotive. With four motors on a car, the system would be efficient at all practical speeds, and if desired, a large part of the energy could be thrown back on the line when the cars are being stopped. In the case of the local trains, a simple calculation will show that a very small part of the total energy expended, is used in overcoming the track resistance, while a very considerable part is employed in accelerating the train and afterward wasted by braking. I have calculated the amount of energy which can be practically saved under the conditions of local and express traffic on the New York underground road, and find that with motors of ordinary efficiency about 45 per cent. can be returned. If storage batteries are used in connection with the central stations, the batteries being located along the line, a uniform load can be thrown on the stations, and their capacity may be reduced to almost one-half, as compared with a system in which the energy is not returned, thus greatly decreasing both the expense of installation and of operation. As it is possible at present to obtain batteries with a rapid discharge rate at very reasonable prices and with a guarantee for repairs, that place them well within the limit of commercial calculations, a system of this kind offers some advantages over any other system that could be applied to the operation of the underground road. An alternating current would hardly be economical for this work, as it precludes the possibility of returning the energy to the line, and as the variable speed required makes it uneconomical as compared with the direct current system using, say, four motors with series parallel control. In the case above cited, shunt motors would be used, and it would be possible to get a contact with the line that could not under any circumstances be broken. The case of the elevated roads is very similar to the one I have cited, except that in existing structures shorter trains would be used, and the cost of equipment for a given number of cars would be somewhat greater.

Baltimore has been the pioneer in almost every branch of transportation. In ocean service, the record of the Baltimore

clipper is a tradition of our maritime supremacy. The Baltimore & Ohio railroad was the pioneer steam road. An electric road from Baltimore to Hampden, built in 1885, gives us a right to boast of our pioneer work in electrical tramways. The immense locomotive for the Baltimore Belt Line tunnel is the first instance of the direct displacement of steam by electricity, and the line over which it is to be operated is the first through steam line to be equipped electrically. The Baltimore & Columbia Railway Company owns in Washington the Eckington and Soldiers' Home Railroad and the Belt Line railroads and has franchises for extensive additions to their present mileage. In Baltimore they are constructing a road in the city and beyond it to Ellicott City, and they have also purchased a steam line running from Baltimore to Catonsville. They have rights of way from the terminus of their Baltimore lines to the lines they own, and are preparing to build in the District of Columbia. The problem offered is not a simple one, but it is one of the most attractive that can be presented to electrical engineers. Speeds of 60 miles per hour are to be used for the cars outside of the city limits, and within the city limits ordinary speed is to be employed. In the District of Columbia, overhead trolley lines are not allowed and some type of conduit will have to be employed. In fact, there is presented almost every problem which must be solved, if electricity is to displace steam in the future with the same rapidity that it has done in the past. Many high-speed electric roads have been projected, a number of them occupying considerable space in the newspapers, but I think this road will be the first to solve the detailed problem of interurban rapid transit.

The last subject which I wish to take up is the electric plant for the Belt Line tunnel of the B. & O. railroad. In this case there is no question of economy in the employment of the electrical locomotives, as the plant adds considerably to the cost of operating the road. The Belt Line tunnel runs beneath the city of Baltimore for a distance of one and one-quarter miles, then to the outskirts of town through open cuts and short tunnels. There is a grade of .8 of one per cent over almost the entire length of the tunnel proper, while one-half mile beyond it there is a grade of one and one-half per cent. Being in the middle of town it would have been difficult to have provided a satisfactory ventilating plant, even supposing that ventilating

plants had been successful in other localities, which is not the case. The managers of the B. & O. Railroad Company wished to provide a satisfactory service, and considered a number of plans for drawing their trains through the tunnel without the annoyance due to smoke and gases. After careful consideration, they concluded that electricity was the most satisfactory means to accomplish this, and the General Electric Company was confident enough of its ability to successfully equip the road to make a contract with the B. & O. company to haul its trains over the Belt Line, the contract being dependent upon the successful operation of the plant. The total length of the line equipped is about three miles, the extension beyond the tunnel being for the purpose of assisting the freight locomotives to haul their trains up the one and one-half per cent grade on the line beyond the tunnel. There are to be three locomotives, and it is calculated that the traffic can ordinarily be handled by two of them. The steam engines are not to be taken off the train, but hauled through the tunnel by the electric locomotive which switches off at the terminus of the line. To operate these machines, a station has been erected which contains 3,000 horse-power of electric generators, and an overhead line has been equipped to transmit the current to the locomotives. With respect to the station itself, there is little that is novel. There are four 750-horse power Allis-Corliss engines directly coupled to generators of the same capacity, the generators having a voltage of 600 at no load, and 700 at full load. The foundations have been partly erected for a fifth unit in case it is found necessary. The building also contains a lighting plant having a capacity for 400 arc lights, and four thousand 16-candle-power incandescent lights. Provision has also been made for an extension to this lighting plant when the stations for the Belt Line are erected. There are two incandescent machines, and one of them will be used to supply the one thousand 32-candle power lamps which have been installed in the tunnel. Perhaps the most novel feature of the plant is the overhead structure that is employed. The conditions to be met were peculiarly difficult, and the ordinary under-running trolley was considered impracticable. The tunnel is very low in places, and the management of the road decided that the conductors could not be placed over the cars, but should be placed in the middle of the tunnel between the tracks. Outside of the tunnel the conductor is still between

the tracks, but is elevated to a height of 22 feet, while inside of the tunnel it is only 17 feet from the top of the rail. The conductor consists of an iron trough made of two Z bars riveted to a cover plate 12 inches wide, leaving a slot one inch wide between the Z bars. In the tunnel this trough is supported from transverse channel bars secured to expansion bolts which are fastened in the top of the tunnel. There is a double insulation, one porcelain insulator being between the trough and the channel bars, and another between the channel bars and the expansion bolts. Outside the tunnel the trough is supported as follows: At distances of 150 feet, light iron columns with cross trusses are erected, and between these trusses are hung catenaries supplied with a number of suspension bolts. Transverse channels similar to those used in the tunnel are fastened to these bolts, and the trough is fastened to the channels. The Z bars are made in lengths of 30 feet, the opposite bars breaking joints with one another, the lengths being riveted together and then bonded with "Chicago" rail bonds. Suspended on the same transverse beams as the trough, are three copper cables of 1,000,000 circular mils area, which serve as feed wires, and which are connected at intervals with the trough, there being, of course, one trough for each track. For the return circuits the tracks are bonded as in ordinary railroad work, there being cross bonds and at intervals connections with a copper cable of 1,000,000 circular mils area carried in a wooden trough between the tracks. The contact arrangement that is to be used consists of a brass shoe traveling in the trough, and connected with the locomotive by a flexible saw-buck arrangement which has a very considerable range in every direction. The current is transmitted to the motors by a copper cable, and in case of the shoe sticking in the trough, a safety pin is arranged to break with any desired strain. Where switches are used, there is a tongue worked by the lever which operates the track switch, and which serves to direct the shoe. This structure, although exceedingly massive and expensive, promises to give an excellent contact at all times, and it requires no care from the motorman.

The locomotives are the most massive in the history of either steam or electrical transportation, and the weight, which amounts to 95 tons, is on eight driving wheels, so that the full tractive power of the locomotive will be developed. On each axle there is sleeved a 6-pole motor, there being considerably play between

the axle and the sleeve, which latter is spring-supported from the frame. In this way any heavy blow due to irregularities in the track is taken through the springs, and the wear both of the track and locomotive is reduced. On the armature shaft are projecting arms which move between lugs cast on the wheels, thus allowing the necessary relative motion between the axle and armature.

The situation in the Baltimore Belt Line plant is this: The station is completed, and is being operated daily. One of the locomotives is on the ground set up and ready to run, and the overhead work is finished with the exception of a short length which was interfered with by a temporary bridge over a cut. The latter has been removed, and the plant should be ready to run this week.

If this equipment proves successful, it will open a limited but important field for the introduction of large electric locomotives. There are in the United States a number of tunnels whose operation is anything but satisfactory at present, which can be equipped as the Baltimore tunnel is. Not only would the economy of the station be increased, but the substitution of electric for steam switching engines would result in a very considerable saving.

This is the last of the subjects that I proposed to consider. In this paper I have not indulged in prophecy, nor have I imagined any apparatus or equipment which cannot be bought to-day in the open market. But to me it seems that the present is a crisis in the history of railroading. Up to the present the steam roads have ignored the competition of electric roads, or they have fought them. To-day they cannot afford to do either. In a few years electric roads will have absorbed practically all of the local traffic and will begin to cut into through transportation. The steam roads cannot afford this, and their only safety is to make of electricity an ally instead of an enemy, and this before it is too late.

The conclusions that I finally reach are:

1. The tendency of passenger transportation on the steam lines has been in the direction of the greatest electrical economy, while the tendency of the freight transportation has been in the direction of the least electrical economy.

2. It will not pay any through line with considerable traffic, having two tracks, to equip their main tracks electrically.

3. With four-track roads it will pay to equip all of the tracks

electrically unless a considerable portion of the business is through passenger traffic.

4. It will pay all the larger roads either to equip a number of their branch lines electrically, or to control competing electric lines.

5. In order to remain on a dividend paying basis, it is imperative that most of the two-track lines either build additional tracks, or control the electric railroads that parallel them.

6. Believing that ultimately all of the traffic will be done by electricity, it is imperative that the managers of steam roads keep in touch with electrical progress.

Discussion.

Vice-President Anthony:—I think it has not been customary to discuss an inaugural address, but the nature of this one is such, that doubtless some would like to comment upon it, and I understand that Dr. Duncan wishes you to express your minds freely. The paper is open for discussion.

Mr. Steinmetz:—While I shall not be able to discuss, and still less to criticise this paper, I desire to add a few remarks in connection with one point that has been brought out by Dr. Duncan, namely, the different methods of operating electric railway motors.

There are mentioned:

1st. The continuous current system.

2nd. The continuous current motor operated from an alternating main line by means of rotary converters.

3rd. The alternating current motor.

I think it may be of some interest to investigate the limits of application of these different systems, and find out in which case the one, and in which case the other is preferable.

All electric roads, as far as they are in operation to-day, or as we expect to see them introduced in the near future, belong under the following classes:

1st. *Surface roads in the interior of cities.*—On these roads the continuous current railway motor with overhead trolley and ground return, operating at a potential of 500 to 600 volts, is used practically without any exception. Only very few roads use either an underground conduit or a double trolley. On city surface roads there is at present no hope of seeing the continuous current motor replaced by any other method of electric propulsion, since the continuous current motor has proved itself entirely satisfactory under the conditions of such a road, and the distances are such that they can easily be reached by 550 volts, or a three-wire system with 1,100 volts between the outside wires. The double

trolley required with alternating current motors, practically excludes them from such roads with many switches and cross-overs.

Only in underground conduit roads can the alternating current motor be expected to find an application on city surface roads. The double trolley in this case is no objection, since conduit roads operate usually with double trolley, and the alternating current system offers in this case the advantage of permitting very low voltage at the trolley lines, due to the possibility of feeding by stationary transformers. Thus we may expect to see the alternating current motor introduced on conduit roads.

2nd. *The second application of the electric motor is to elevated roads.*—Here the continuous current series motor is just being introduced, and, as far as I can see, I do not believe that there is any hope at present of replacing it with the alternating motor, due to the particular nature of the elevated road service, where trains never run at full speed. Take as an instance the Manhattan elevated road in New York. Excluding express trains, I do not believe that on this road a train ever runs at full speed, because before it has reached that point it has already approached so near to the next station that it has to slow down. Now you see very readily that the alternating current motor, while it can operate at its proper speed with very high efficiency, and can get any starting torque desired, nevertheless does not give this flexibility of speed, but while accelerating, has to run on the rheostat, and thus does not give the same efficiency as the continuous current motor under the same condition. For this reason the alternating current motor is less suited for elevated roads, the more so, since the main advantage of the alternating current system, the opportunity of feeding by means of stationary transformers, is of no essential value for elevated roads which are of moderate length, and have a very heavy traffic; and where it is thus possible, with a comparatively small investment, to feed the road by continuous current at 500 to 700 volts, or even more, from one or a few power stations. Thus, these two fields of application will be held by the continuous current motor for a long time to come.

3rd. Another field in which the electric railway motor is rapidly gaining is in the *suburban and interurban traffic*, or those lines which extend from the city roads far out in the country, or connect adjacent cities, as for instance the net work of railways stretching out from New York City along the Hudson and East Rivers, or from Boston out to Lynn, Salem, Dorchester, etc.

If the length of these roads becomes considerable, it becomes impossible to feed by continuous currents from one central station, and thus some other method becomes necessary. Either you have to put frequent power stations along the road, which is to say the least, awkward and inconvenient, or you have to use alternating current, and in the latter case two possibilities exist: either continuous current motors on the cars, supplied by rotary converters from alternating main lines, or alternating motors on

the cars supplied by stationary transformers. Both of these methods offer advantages and disadvantages.

The *system of rotary converters* has the advantage of allowing the use of a standard continuous current railway motor which is able to run over the city lines also, so that the same cars and motors can be used on city surface roads and suburban and interurban roads, the rotary converter merely taking the place of a supplementary central station. However, in general the speed at which the suburban roads are operated will be higher than the speed of city roads, and thus for this reason special motors, that is, special cars will be required. Furthermore, the use of a commutator makes it desirable not to exceed 500 to 600 volts at the motor. This voltage means a frequent use of rotary converters along the road, which is objectionable, since the rotary converter as revolving machinery, requires some attention and supervision, that is, in reality constitutes a substation.

The *alternating current motor* has the disadvantage of requiring a double trolley. This may not be very objectionable on suburban roads with few switches and crossings. It has, however, the essential advantage of running at a fairly constant speed, independent of the load, and will not race when running down hill, but will in this case return the power as generator into the line; nor will it slow down when climbing hills. This is quite a valuable feature in single track roads, where at present with the continuous current motor the car going down hill has usually to wait on the switch for the car going up hill. Furthermore, the alternating current motor is more reliable in its operation, and since the alternating main current enters the motor field only, which is stationary, a higher voltage is permissible, that is a greater distance between the supply transformers. The main advantage, however, is the possibility of feeding the line by stationary transformers, which need no supervision, but are to be considered merely as a part of the feeders. Thus, on these roads, wherever it is not absolutely essential to run the same cars over continuous current city roads, the use of alternating current railway motors on the car, supplied from an alternating current trolley line, will be preferable to the system of rotary converters.

4th. A further field for electric railroading is to be found in *high-speed, long-distance roads* for mostly passenger traffic, connecting important cities. Thus far nothing has been done in this line, although considerable discussion has taken place. I am sure that the future will bring such roads. It is obvious that in this case only alternating current motors are applicable, mounted directly on the axles and fed from high potential mains by transformers. The speed of these roads must be very high, since steam locomotives have already reached a speed of about 100 miles an hour, and there would be no demand for the electric motor if it did not offer an essential advantage over the steam locomotive, and such advantage can only be found in the possibility of using very high

speeds, due to the absence of reciprocating motion. Thus speeds of 150 miles per hour maximum, with an average speed of 100 to 120 miles per hour, will be just as safe as the present steam locomotive speeds.

The objection has frequently been raised against the alternating current motor for railway service, that it does not give sufficient starting torque. This objection holds no longer, for the starting torque of alternating induction motors, for instance of the three-phase type, far exceeds that of the continuous current motor. Theoretically this is easy to understand. The torque of a motor—starting torque as well as running torque—is proportional to the product

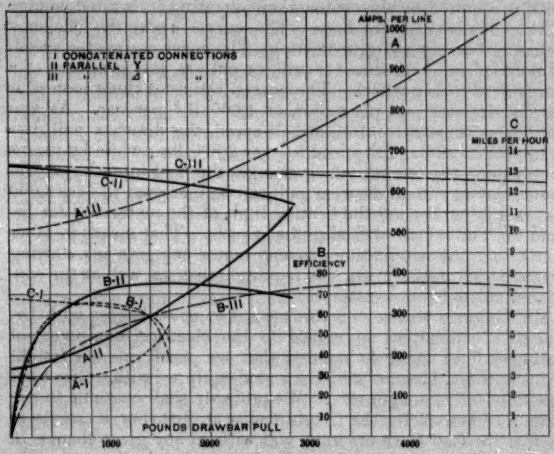


FIG. 1.—G. E. I. Three-phase Railway Motor. Drawbar pull with 33" Wheels and Two Motors per Car.

of armature current into field magnetism. In the continuous current motor at normal running, the field must be fairly near saturation. Thus an increase of field magnetism is possible to a limited extent only, and an increased torque, therefore, requires a nearly proportional increase of current. In the alternating current motor, however, the field is very far from saturation at normal running, and thus can in emergencies—as when starting on a curve or when climbing heavy grades—be doubled and tripled. Therefore, to get four times the torque in the alternating current motor, by means of doubling the field strength, only twice the current will be required, while the continuous current motor probably requires three or more times the current.

Furthermore, the production of heat in the alternating current motor is distributed over the whole apparatus, and thus a much greater heat can be taken care of for a limited time.

I have here the testing record of a car equipment with two three-phase induction motors (Fig. 1). They are designed to operate with the same speed and are of about the same size and weight as the standard General Electric Company's continuous current railway motors, G. E. 800. They are controlled by a method which I have devised, and whereby it is possible to operate them at full efficiency and half speed as well as full speed, thereby offering the same advantages as the series parallel control of the continuous current railway motor. The curves A denote current per line required by this motor when operating at its rated voltage of 110 volts between the lines. The curves B give the efficiency including bearing and gear friction. The curve C gives the speed, all as function of the drawbar pull, or pull at the periphery of a standard 33 inches wheel. The normal rating of these motors is 800 lbs. drawbar pull per motor, or 1,600 lbs. per car. As you see, in concatenated control, at half speed, the drawbar pull rises to 1,600 lbs., and at full speed to over 2,800 lbs., while by means of an emergency switch which changes the field intensity of the motor, the maximum drawbar pull can be increased to over 8,000 lbs., that is far beyond the heating limit of the motor and far beyond the pull which will slip the wheels. That means in other words, that the alternating current motor can give any starting torque which possibly can be required, just as well as the continuous current series motor.

MR. OBERLIN SMITH:—I think most of us will agree with Dr. Duncan's conclusions in regard to the electrical equipment of passenger lines, but I do not see that we need rule out freight trains entirely, because we have a road equipped with trolley lines especially for passenger cars. We probably shall continue to run steam locomotives for the freight trains at first, but it seems to me that we shall learn ere long, and without any great change in the general system of freight traffic, how to electrically run freight cars too. It must be remembered that the long freight trains we now have are an *effect*, to some extent, of the steam locomotive system. Just as soon as the locomotive is gone for passenger work, new schemes will doubtless be devised. There would seem to be no inherent reason why we cannot run freight cars, one, two or three together, dividing up these long trains, which in many respects are a nuisance to railroad men and a source of danger and trouble, especially where they have to be divided for transfer at branch roads, and to leave a few cars at way stations, and all that. It seems to me very likely that when we once learn how to get passenger cars rapidly and cheaply over the roads, that freight cars also will gradually be run in the same way. So I do not think we should assume that we shall have to perpetually keep the steam roads running for freight, although

it may be that we shall. That is a point that has not been developed yet. Of course, it is true as has been stated, that the great objection to shorter freight trains is a purely economic one—consisting of the extra cost of labor. Against this we have the saving in locomotive dead weight, etc., and (a point that has not been mentioned) the much smaller liability of the occurence of the expensive freight wrecks to which long trains are so subject.

One thing Mr. Steinmetz said was to the effect that unless we could run very much faster, than, say 100 miles an hour, (or the somewhat hypothetical 112½ miles, of recent rumor), that they do run with steam locomotives, there would be no object in having electricity. I think this is a mistake. There is a great deal of advantage in having electricity, even if we do not run as fast as the locomotives run. There is, however, little question but that we can run faster, because we get rid of the threshing and pounding in the reciprocating parts of the locomotive, and get a merely rotary motion, with a perfectly simple machine, instead of a rather complicated one. But we can also run faster for a given price for coal and labor, or we can run at the same speed at a less price, for one very important reason, that we get rid of the dead weight of the locomotive to a very considerable extent—the dead weight of the motor, etc., not amounting to nearly as much. And, too, we shall probably get rid of some of the dead weight of the cars which are now most abnormally heavy.

The railroads of this country are carrying passengers all over the land with from one to six tons dead weight for each passenger.[1] We cannot expect the steam railroad men, who are rather conservative, and very properly so, in the interests of their employers, to change suddenly, or adopt any very radical measures; but when a crisis like this comes, when we begin to make sudden and comprehensive changes in the way of "trolleying" old roads, the time seems to be ripe for other changes. I have no doubt, whatever, that we shall learn how to make our cars very much lighter than we do now, with a consequent decrease in cost of coal and decrease in accidents due to excessive momentum; and all this by doing away with the locomotive. Therefore we shall have an advantage, even if we cannot run faster—although I personally do not question but that we can run very much faster.

Another point that is not generally talked about is the immense advantage to passengers, and consequently much greater popularity with the public, of the electric car, because of the total absence of the soot and smoke and whistling, together with other nuisances incident to the locomotive. This is going to increase the *traveling habit* and bring in more travel than we now dream of. That it is possible by electricity to get these enormously high speeds of 120 to 150 miles an hour, as alleged in the newspaper articles referred to by our President, by the use of electricity is

1. For an analysis of this dead weight, see my article on Railway Reform in *The Forum* for January, 1891.

probably true, considering the advantages just referred to of not having the rattling and pounding of the reciprocating motion of the present locomotive and all that, but who of us here to-night, if he had ever so nice an electric car, would like to ride over any of the tracks that we have to-day at 150 miles an hour? Possibly those without families or those with big life insurance policies might do it, but I for one should not want to. Sixty or seventy miles an hour is as fast as I care to go on these present railways, where there is nothing but a 1½ inch flange to keep me out of eternity.

We must, before running at those enormously high speeds, have a new system of road beds I do not know just what it is going to be, but it will, I am sure, be something vastly different from the present one. We must absolutely abolish switches and crossings and such things, as well as the presence of cattle and men on the tracks, and there must be some way of confining the cars better than by their own weight and these little wheel flanges. We shall confine them to position in some other way, so that the one great and to-be-dreaded evil of derailment will be impossible. Collisions we shall escape by the use of electric blocking, etc., and by more perfect operating systems. When we learn to avoid derailment absolutely, as well as collisions; when we get rid of our smoke and soot and our reciprocating parts, and our excessive dead weight, then, and not till then, shall we attain really high speed, combined with comfort and safety. All this the coming century will no doubt see, and probably may see rather early in its course.

PRESIDENT DUNCAN:—I have listened with a great deal of interest to the remarks that have been made. Perhaps the uses of the different methods and their limitations were correctly stated by Mr. Steinmetz. But I did not care to take the question up. I think we can offer the steam railroad people, systems that will operate their passenger traffic more economically than it is now being operated. But the question I wished to consider was whether they are in a condition to accept the offer? There are only a few roads in the United States that are in a condition to accept the electrical benefits we can give them, because no two-track road, without disorganizing its traffic, can get the advantage of electrical transportation. We cannot at present change the method of freight transportation. I am not considering what is going to happen in the future, I am considering the conditions as they exist at the present time. You cannot disorganize the freight traffic, you cannot disorganize through traffic, and with those two kinds of traffic on two tracks, you cannot possibly compete with a parallel line running a regular tramway service. It is not a question of which way we want to equip these tracks, but the thing is that the steam people must give us the tracks to equip, and to secure the benefits of electrical traction, we must have four tracks on through roads, and even with four tracks, some roads will find it difficult to equip.

We cannot compete for freight traffic by electricity except by using self-contained electric locomotives, in which the electrical apparatus is a mere gearing between the steam and the axle. As far as the principle goes there would be no difference in the character of the service between this and the ordinary steam equipment. But a freight traffic by a trolley system will not be as cheap as the steam traffic. At the present time the condition of affairs is this: The steam roads must compete with the electric roads that are paralleling them, and which are cutting down their receipts, and I think this can only be done by giving separate tracks for the electric service, or by controlling competing roads. As Mr. Steinmetz says, there are a number of ways in which we can equip the roads electrically. Although he has projected a little into the future, yet I think he has pretty well stated the kind of service we ought to have on the different kinds of roads. But at the present moment, even if he were prepared to sign a contract for any one of the different types of equipment on any one of the different types of road, I say there are not three or four steam roads in the United States that are prepared to take advantage of it; and that was the point I wished to take up in my address.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

COMPOUNDING DYNAMOS FOR ARMATURE REACTION.

BY ELIHU THOMSON.

Considerable attention has recently been drawn to the subject of means for counter-balancing or preventing armature reaction in dynamo-generators or motors. The valuable paper of Messrs. H. J. Ryan, and Milton F. Thompson, read before the INSTITUTE at its meeting on March 20th, called forth considerable discussion as to the actual utility or need of added devices, which undoubtedly render a machine more complex, but which can certainly be made to obliterate armature reaction or overcome its effects. The opinion which seems to prevail amongst engineers is, that by taking advantage of the best principles of design, the output of our machines is not limited by armature reaction, but rather by heating, or the capacity to diffuse that heat which is sure to be produced during operation.

The writer's views are in accord with the general sentiment indicated by the discussion of the paper in question, excepting that he conceives that it may on occasion become desirable to possess a structure, either generator or motor, in which a load which would inevitably overheat the machine if continuous, may be borne without destructive results for short periods only. The development of engineering work may in fact demand, occasionally, machines which would be regarded as emergency machines, to be operated with the highest possible loads for short periods. It is sometimes desirable that a dynamo be adapted to driving at different speeds while maintaining the same potential at the terminals, as in the case of direct driven dynamos coupled

with engines of different makes and speeds. Such an adaptation would require a change in the armature turns, or in the field excitation, the former demanding a reconstruction amounting to the production of a special type, while the latter, change of field strength, might involve such a weakened field at the higher speeds as would be incompatible with proper commutation. In such cases means and methods for securing proper commutation and neutralizing reaction may become quite useful. The subject itself has been worked upon by the writer as far back as 1879. At first a peculiar disposition of the field coils and pole pieces was selected, unfavorable to armature reactions, and later in a a patent applied for by the writer in the year 1885, the series coil of a compound-wound machine was so disposed as to add, under load, a magneto-motive force to the field in the region of armature opposition, and as a consequence to diminish somewhat the magneto-motive force of the field where the reaction of the armature was positive, or assisting.

In the present paper, however the writer desires to bring to the attention of the INSTITUTE a different type of dynamo, worked upon by him some three or more years ago, in which there is no series winding whatever, though the machine is in effect compounded, or over-compounded at will.

It is expressly to be understood at the outset that the present paper is not intended to advocate the disposition described as a desirable commercial structure, or even as one which will be likely to come into practical use on any scale. On the contrary, it is believed to be open to objections which would take it out of competition with ordinary types in which the compounding effect is secured by the series coil or load circuit wound as usual as a part of the field energizing conductor.

The machine is, however, interesting as bringing out forcibly the capability of the armature current to neutralize its own effects in a proper structure and maintain, or even increase, the potential at the brushes under heavy loads. In fact the current in the armature in the type of machine herein treated, is made to react under load to magnetize a portion of the field structure which at no load is neutral or nearly so. The reaction may thus be made to give rise to a magnetic flux sufficient or more than sufficient to compensate for its effect in diminishing the flux of the other or excited portion. The result is accomplished by dividing each field pole into a portion which is left unwound and a portion

which is wound and excited in shunt or separately. At no load only, the wound polar portions act to generate the open circuit E. M. F. As the load is put on, the unwound or dead poles become active in consequence of a magnetic flux developed in them by the armature currents themselves, that is, in consequence of the M. M. F. generated by the current in the winding of the armature itself. The disposition of the poles in a bipolar structure would be represented by Fig. 1, where A A are the excited poles, or wound field cores, under the fringe of which commutation is effected, while D D are the "dead" poles or sections of polar surface unenergized at no load. A dotted line *a a* may pass through the neutral or non-polar portion of the armature iron, threaded by all field lines on one side, while the lines *b b* may indicate the diameter of commutation on which the brushes rest. In such

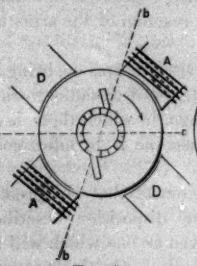


FIG. 1.

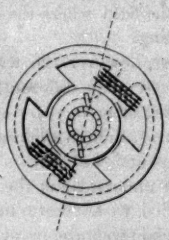


FIG. 2.

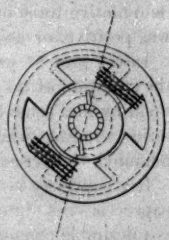


FIG. 3.

a structure by choosing the position and spread of the "dead" poles in relation to that of the wound or excited polar portions, and adjusting the M. M. F. of the initial field relatively to the turns on the armature and the speed of driving, the effect of compounding or over-compounding may easily be obtained. The "dead poles" may he made adjustable in position so as to vary the effective M. M. F. of the armature upon them and various changes in relations of the parts are conceivable.

In Figs. 2 and 3, an attempt has been made to represent the magnetic flux under no load and under load respectively. In Fig. 2 the flux in the air-gap between the excited poles A A and the armature may be considered as of uniform density except at the edges, while in Fig. 3 it is, under the same poles, somewhat diminished towards the diameter of commutation. In Fig. 2

the dead poles are without flux across the air-gap, while in Fig. 3 the density increases from one edge to the other in the direction of rotation.

Fig. 4 is from a photograph of the dynamo constructed in accordance with the principle under discussion. It is multipolar, having four wound poles and four dead poles alternating in position around the armature. The latter is of standard iron projection type being in fact identical in construction and dimensions with the armatures used about three years ago in reg-

FIG. 4.

ular four-pole dynamos of the marine type of the Thomson-Houston Electric Co.

The principal data of the armature construction are as follows :

Diameter over all	17	inches.
Length (laminations)	8	"
Radial depth of laminations	4	"
No. of projections	87	
Width of slots	.34	inch.
Depth of slots	.75	"

The armature is series drum-wound and has two conductors in each slot. The commutator has 87 segments. The new field

system was constructed of two rings of cast open hearth steel having heavy lugs, four in number, projecting laterally from each ring on one side, and forming the dead poles when assembled in the machine. Separate castings for carrying the field coils and constituting the active poles were made, wound and bolted between the two ring castings of the field. The arrangement will be understood at a glance from an inspection of Figs. 5 and 6. Fig. 5 is a section of the field in a plane passing through the dead poles and the axis of the armature, and Fig. 6 is a similar section through the active or wound poles. The wound cores have a section of $3\frac{1}{2}$ in. $\times$ 8 in. and are of steel. The field was bored to $17\frac{1}{4}$ in. thus giving a clearance of $\frac{1}{8}$ in. around the armature. The excited or wound poles covered each about 5 inches, the dead poles each $5\frac{1}{2}$ in., leaving spaces between wound and dead poles of about $1\frac{1}{2}$ in. The face of each dead pole is $5\frac{1}{2}$ by 8 in.

The coils on the active poles can be connected in shunt to the

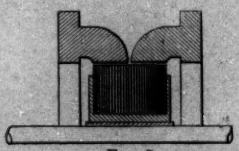


FIG. 5.

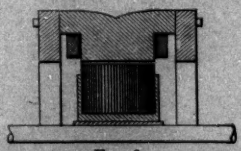


FIG. 6.

armature terminals with a variable rheostat in the branch, or separately excited as desired. It was found that for the purposes of test that the latter arrangement was most satisfactory as the exciting current could then be adjusted to any given value and would remain undisturbed by variations in the potential difference between the brushes or terminals of the machine.

Fig. 7 shows the relation of volts at the terminals to varying exciting current at no load (full line) and at 30 amperes load (dotted line) with a speed of 800 revolutions per minute. It will be noted that the load has caused an increase of voltage particularly at the relatively higher excitations. The normal current of full load for the armature as constructed and used in the regular multipolar field was 140 amperes, and it was found that as the load was increased steadily during a run, the potential was not only maintained but increased with each increment of load, thus showing an over-compounding effect. This effect was less marked

when the initial excitation was weak; as when less than three amperes traversed the field coils. The over-compounding under load was, of course, still more increased when the field coils were connected in shunt to the armature. Thus, at a little over 750 revolutions per minute with an exciting current of four amperes, the open circuit volts were 84, rising to 104 when a load of 130 amperes was put on with an increase of the exciting current to 4.8 amperes.

It was noticed that on any considerable increase of load being made, the potential rose in some cases as much as 5 or 6 volts.

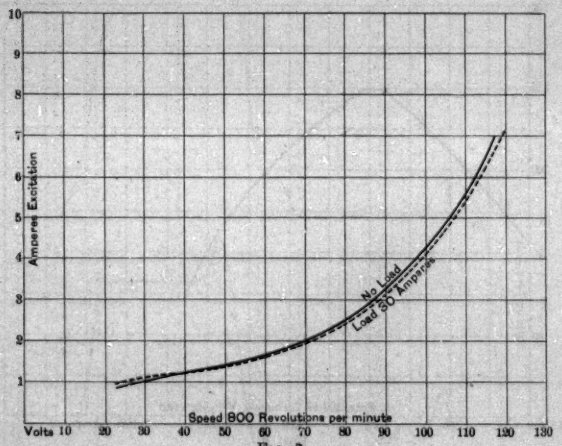


FIG. 7.

above the point at which it would remain; or which it would reach after a short interval. Similarly it was found that the sudden taking off of load caused a temporary fall below the stable voltage under the new or diminished load conditions. This curious effect was traced to the difference of time between that needed to build up or cut down the flux in the dead poles, as compared with that required to cut down or build up the excited poles, which, being wound with wire, were naturally more sluggish under the conditions of use. Currents would be induced in the coils under each change of flux, which change itself would

thereby be rendered more gradual. The dead poles being unwound could respond more rapidly. Any increase of load would of course tend to break down the wound poles and to increase the flux in the dead or unwound poles, and the taking off of load would have the opposite effect.

Fig. 8 shows a compounding curve obtained under a constant excitation of four amperes at a speed of 790 revolutions, the load being varied from 0 up to more than thrice the full load. It will be noticed that the potential at first increases, and only breaks down under extremes of load. The final breaking down

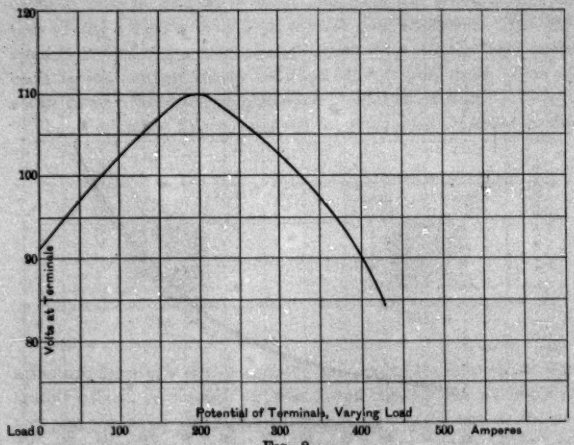


FIG. 8.

is doubtless due to saturation of the forward portions of the dead poles, together with the armature core projections. Part of the drop was undoubtedly due to resistance at the brushes which were of carbon, and by no means fitted to conduct off such heavy currents. Taking this drop and the drop over the armature conductor itself, it is not surprising that at the high loads the potential should fall off.

A horizontal plotting of the potentials generated in the armature coils under no load obtained by the two brush method of Dr. S. P. Thompson, is given in Fig. 9, the relative positions of

the wound and "dead poles" being marked in dotted lines, and the arrow indicating the direction of movement of the armature relatively thereto.

Fig. 10 gives the same plotting under a load of 100 amperes and accentuates the effect of the armature reaction in magnetizing the dead poles. The curves are only approximate indications

Fig. 9.

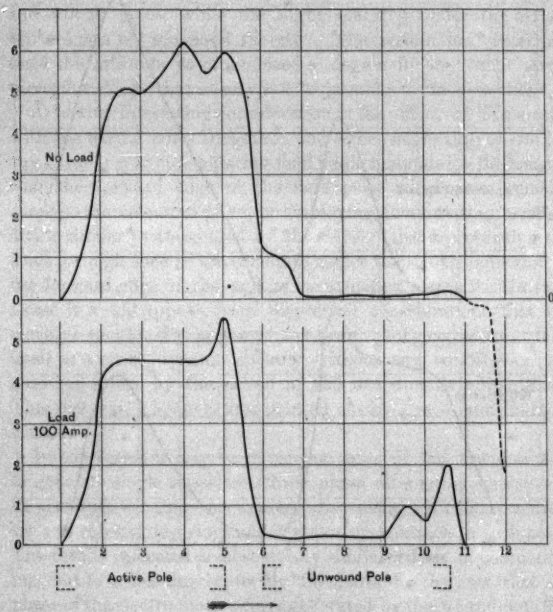


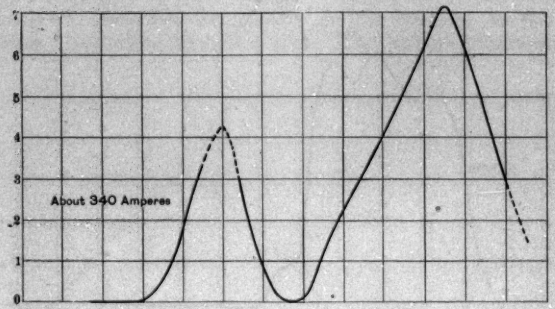
Fig. 10.

owing to the fact that the number of points at which readings were taken was less than was desirable, and because in some cases it was difficult to maintain all conditions unchanged, particularly with the very heavy loads.

Figs. 11 and 12 show a similar plotting for abnormal or extreme loads. The former shows how completely the wound pole has

been broken down by armature reaction, and how the unwound poles have now become the chief working field poles, or rather how the armature winding itself has furnished the field for its own cutting. A calculation of the flux density at the forward edge of the unwound pole shows that the magnetization has risen to saturation. The other parts of the pole are shown to be still

FIG. 11.



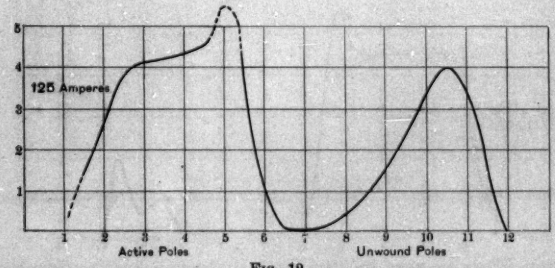


FIG. 12.

susceptible of increase of flux, but their relation to the armature is far less favorable for its generation.

The machine described is probably chiefly interesting from a theoretical aspect. Still it shows clearly that so far as the effect of the series field on compound wound machines is concerned, the electrical engineer has other resources at his command giving similar results. It cannot be doubted also that the design of armature and field might be considerably improved with special

regard for the particular feature of compounding. A feature of the machine which developed itself when carbon brushes were used, was that even at heavy loads the brushes could be set back from their maximum position, or true diameter of commutation in this case, and that the movement was attended with little, if any increase of spark, while the potential steadily went down. It was thus easily possible to adjust the potential by a backward movement of the brushes in the space between the unwound and wound poles, while the slight sparking under the carbon brushes was not increased thereby. The writer has never noticed this effect in so pronounced a degree in any other structures, but thinks that it may not be peculiar to this machine.

A further interesting consideration is the effect of dispensing with the wound poles altogether, and either neglecting to employ any reversing or commutating field while maintaining the brushes near the forward edge of the field poles which now remain, namely, the unwound poles, or employing commutating arrangements similar to those used by Mr. Sayers; that is, returning the leads through slots in the armature under the strong induction of the forward edge of the pole as the armature leaves it. In such a case it would appear from theoretical considerations that the machine should, if it possessed any permanent magnetism, excite itself as a series dynamo entirely without any winding on the field and solely by the action of the armature winding itself. This fact was, I believe, first pointed out by Drs. J. and E. Hopkinson.

In conclusion it may be stated that tests of the machine used to generate single phase and three phase alternating currents in its armature winding were made by dispensing with the commutator and substituting rings and connections common in such cases. The results indicated a substantially similar effect of compounding, but to a less degree, owing no doubt to the fact that the phase of the electro-motive-force generated by the wound pole flux would not coincide with that due to reaction on the dead poles, since the position of the poles with relation to any portion of the moving wire is different at the same instant.

The Secretary announced that the American Telephone and Telegraph Co. [long-distance] had extended to the members of the Institute the courtesy of their lines throughout the United States during the continuance of the meeting.

[Recess until 10 A.M.]

A paper presented at the 12th General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

ELECTRIC POWER IN FACTORIES AND MILLS.

BY F. B. CROCKER, V. M. BENEDIKT AND A. F. ORMSBEE.

Introduction.

The application of electric power distribution to the operation of factories and mills, including the driving of the various machines and other apparatus, is the latest and one of the most important problems toward which attention is now being directed, the question being one of extreme prominence both from an economical as well as from an engineering standpoint.

In comparing two or more different systems of power distribution, the fundamental basis of comparison is generally that of dollars and cents. This is certainly correct, as far as it goes, but unless a very decided difference be found between the costs of running under the various systems, it may be found that other factors enter; factors which cannot be estimated in dollars and cents, namely, questions of desirability and convenience. Without considering any tests whatever, there are several exceedingly advantageous points in the use of motors in factories which are almost self-evident, such as: 1. Clear and unobstructed passages and head room, the latter facilitating the use of travelling cranes. 2. Ease of shifting the tools from place to place, possibly necessitating the placing of a starting box and the putting up of a little extra wire, as compared with the inconvenience and trouble of setting up and adjusting a line of shafting, hangers, belts, etc. 3. The economy due to the ability to run a single tool without necessarily starting the whole factory or at least a complete section. 4. The running expense is entirely stopped when the tool is shut down. 5. The absence of the drip of oil from overhead shafting. 6. The tools may be placed at any desired points

almost regardless of the distance. 7. It is not necessary to arrange the tools parallel as in the mechanical system. 8. A wider range of speed is possible. 9. Less damage caused by a fuse blowing, than by a belt slipping off in case of accident or excessive load.

Considerations like the above have great weight in deciding a question such as that under discussion, and there is no doubt whatever that in most cases they rise to such prominence that they warrant a complete change from the old system to the new, even though there is no gain in economy or increased output. In most cases, however, it has been conclusively shown that considerable saving and increase in production is obtained, one test showing a very considerable percentage of increase in the output. The partial, if not the complete, displacement of the old method by the new is only a question of time, and it was the appreciation of this fact that induced the authors to undertake the determination of the power actually required to run the various tools and machines as used in ordinary practice.

Historical Notes.

The general use of electric motors in factories is comparatively recent, hence the history of the subject is necessarily short, although Froment, about 1850, used an electric motor to drive tools in his workshop. About five years ago motors were in operation in the works of the Thomson-Houston company at Lynn, the Crocker-Wheeler company and the C. and C. company. Shortly afterward the great German works of the Siemens and Halske company and the Allgemeine Elektricitäts Gesellshaft began using motors to operate sections of their factories. From that time to the present, the use of motors has extended rapidly, until now they have been adopted in many factories all over this country and to a less extent abroad.

Practical Tests.

In the tests which follow, the power required to drive the tools was obtained by placing an ammeter in the circuit of the motors running the various machines and groups of machines, and taking readings every few seconds, the frequency of the readings depending upon the nature of the tool and the work it was doing. The potential was practically constant at 110 volts, not varying more than one or two per cent. The first tests were made at the factory of the Crocker-Wheeler Electric Co., at Ampère, N. J., and the machines tested and the results obtained were as follows:

1. *Large Boring Machine.*—This machine was driven by a 1½ H. P. motor, speed 1,200 R. P. M., mounted directly on the frame of the tool, the reduction in speed being obtained by the use of gearing. During this test, which lasted three hours, the machine was used for turning down a commutator for a 100 H. P. dynamo. The average current drawn was 8.3 amperes, representing 1.23 H. P. at 110 volts. Before the run was finished, the speed of the tool was increased by changing the combination of gears, and during this time the power required was 1.43 H. P. When the machine was started from rest, the rush of current was considerable, the average being 17.75 amperes, representing 2.6 H. P. It will be seen that this motor is well suited to the machine, the average load being very close to the rated power of the motor.

2. *Drill Press.*—A drill press was run by a 1 H. P. motor, speed 545 R. P. M., mounted on a shelf at top of press and belted down to countershaft at bottom, and thence up again to main shaft of machine, thus securing a reduction of the speed. This machine was boring the faces of the cast-steel pole-pieces of a 10 H. P. motor, two cutting tools being used. The test lasted 4 hours and 40 minutes and during this time the pole-pieces for three motors were bored. The first run covered 1 hour and 10 minutes and the average current was 2.92 amperes, representing .43 H. P. It required 15 minutes to replace the completed pole-piece by another one. This second piece required 2 hours and 32 minutes to finish, and the average amperes were 2.82 or .41 H. P. This time it required 17 minutes to replace the piece, and then the machine ran only 23 minutes until closing time. The current for this short run was 2.81 amperes, representing .41 H. P. The total length of time the machine was running was 4 hours and 5 minutes. Therefore power was supplied to the motor 86 per cent. of the time of the test.

3. *Drill Press.*—This machine was similar to the one preceding, but the work was different; namely drilling half inch holes in cast-iron bearings. The average current was 2.86 amperes, which represents .42 H. P.

4. *Drill Press.*—This tool was the same as the other two and the work consisted in boring the inside of cast-iron bearings. The average in this case was 1.9 amperes or .28 H. P. It will be noticed that in the case of these three machines a motor of one-half H. P. would be of ample size to do the work.

5. *Punch Press.*—This was a small punch run by a one H. P. motor mounted on the base of the machine and belted to its heavy fly-wheel. The speed of the motor was 700 R. P. M. This tool was punching slots in sheet iron disks for a 10 H. P. armature, there being 28 slots in each disk. The motor was turned off every time a disk was replaced, but it did not come to a dead stop as the inertia of the fly-wheel was so great. Readings were taken every five seconds and the time of turning on and off the current was noted. The test lasted 57 minutes, during which time the current was turned on for 35 minutes and 45 seconds, or 62.7 per cent of the time. The average current was 4.86 amperes, equivalent to .71 H. P. The rush of current at starting varied from 7 to 15 amperes, depending upon the haste of the workman in turning on the starting box.

6. *Gang Drill.*—This tool was driven by a one H. P. motor, 1,000 R. P. M, mounted with vertical shaft in frame of the machine and belted directly to the three drill spindles. The material drilled was cast-iron, and the sizes of the holes were $\frac{1}{4}$ in. and $\frac{3}{4}$ in. The average of the readings taken was 4.75 amperes or .7 H. P. When the drills were running free the motor took 3.5 amperes. Thus the power required to overcome friction was 74 per cent. of the power used while drilling.

7. *Group of two machines, one lathe and one milling machine.*—This group was driven by a three H. P. motor, belted to a short line shaft, from which belts ran to the countershafts above the two machines. The average current was 10.04 amperes, the power being 1.48 H. P. In this test, special attention was paid as to which machine happened to be running free, cutting, etc., with the results given in the following table.

Class of Machines and Work.	Amperes.	H. P.
Milling Machine Running Free—Lathe at Rest.....	5.67	.836
Lathe " " " —Miller " "	7.36	1.085
Both running free	10.	1.47
Milling Machine Cutting—Lathe run free.....	10.33	1.52
Lathe Cutting—Milling Tool running free.....	14.42	2.12
Both tools cutting.....	15.4	2.28
Cutting rate increased on the lathe.....	17.8	2.61

8. *Group of Six Machines, Consisting of* 1 *Milling Machine (Small)* 2 *Lathes* (10 *or* 12 *Inch Swing*), 1 *Grindstone*, 1 *Drill Press and* 1 *Small Punch Press.*—The last named tool was not run at all during the test, and the grindstone ran continuously. This group was run by a one H. P. motor, belted to the usual

ceiling line shaft. The average current required to drive these machines was 5.86 amperes, representing .86 H. P. Thus this motor ran at about its most economical load.

9. *Group of Seven Machines*, 1 *Planer*, (*Small*) 1 *Grindstone*, 4 *Lathes*, 1 *Hand Turning Lathe.*—A three H. P. motor was used to drive this group, being belted to a line shaft, the same as the previous groups. The current was 13.36 amperes or 1.97 H. P. When the entire group was in use 2.65 H. P. were required.

10. *Group of* 7 *Lathes and* 1 *Grindstone Driven by a* 3 H. P. *Motor.*—The average current was 9.92 amperes and the power required was therefore 1.46 H. P. The power used by the motor when different numbers of lathes were running is shown by the following table:

Number of Lathes Running.	Amperes.	H. P.
One	7.76	1.14
Two	9.16	1.35
Three	10.69	1.58
Four	12.23	1.8

Thus in a group like this, it only takes 63 per cent more power to drive four lathes than it does to run one, the reason being the fact that it probably takes about one horse power to drive the countershafts.

11. *Group of Two Machines, a Large Punch Press and a Large Planer.*—The motor for running this group was placed on the floor, and drove a short line shaft on the ceiling by the usual form of belt. The rated capacity of this motor was 7½ H. P., and its speed was 1350 R. P. M. The punch press did not run during the test. With the planer idle and the motor driving the shafting and belting alone, the current was 15.5 amperes, which represent 2.3 H. P. While the planer was at work the motor required 33.1 amperes or 4.87 H. P. As the loss from friction in the shafting is nearly constant under the variation of load, the power required to overcome this friction was 47 per cent. of the total power used. When the bed of the planer reversed from its slow cutting stroke to the comparatively rapid return stroke, the current increased to 52 amperes, showing an expenditure of 7.6 H. P. for a few seconds. This tool was planing the frame of a 90 K. W. multipolar dynamo, the material being cast-iron.

12. This group was a very large one, consisting of 20 machines;

8 lathes, 4 milling machines, 3 planers and shapers, 2 grindstones, 1 vertical shaft grinding machine, and 3 small tools. The motor in this case was rated at 10 H. P. at 750 R. P. M. A Thomson recording wattmeter was placed in the circuit of this motor for one afternoon. At the end of this time the wattmeter showed a total of 17,854 watt-hours used, and as the time was five hours, the average power was 3,571 watts or 4.78 H. P. The average number of machines running was 13, most of the lathes being in use the greater part of the time. An ammeter was inserted in the circuit of the motor for a few minutes, and it was noted that the work was very steady, the current not varying more than 3 or 4 amperes at any time.

13. A group of five machines run by a 3 H. P. motor was next tested. Of these five machines, one was a lathe with 17 inches swing and 8 feet bed, one was a slotter, and the other three were lathes of 12 or 14 inches swing. The average amperes were 7 and the power 1.03 H. P.

14. The last tool tested at this factory was a large new engine lathe, which had just been set up, of 50-inch swing. This tool was driven by a 3 H. P. motor mounted on an iron bracket built in the base of the machine. The motion of the motor shaft is transmitted to the tool by gears, thus doing away with all belts. The work done was turning a 5¼-inch steel shaft for a 200 K. W. dynamo, facing the ends etc., the cut being very light, as the work was only preliminary. The average current consumption was 11.4 amperes. Hence the average power was 1.68 H. P.

The following tests were made in the erecting shop of the De La Vergne Refrigerating Machine Company, at Port Morris, N. Y.

1. *Planer.* A large planer, 120 inches between posts, by 108 inches high, by 22 feet bed was driven by a C. and C. motor of 15 H. P. The voltage employed was supposed to be 220, but due to an incorrect station voltmeter the actual potential only averaged 190 volts on the morning of this test. The average current was found to be 20.08 amperes which at 190 volts represents 5.11 H. P. At the reversal from the cutting to the back stroke, the current increased to 85 amperes, equivalent to 21.65 H. P. The power required during the cutting stroke was 4.76 H. P., while on the return stroke the average was 5.73 H. P.

2. *Drill Press.* A drill press driven by a 5 H. P. C. and C. motor was tested in the afternoon. The potential was raised be-

fore this test, so that the average was 215 volts. The power required when drilling variously sized holes is shown in the following table:

Size of Drill.	Amperes.	H. P.
Running Free.	3.	.865
$\frac{7}{8}$ in.	4.07	1.23
$\frac{15}{16}$ in.	4.37	1.26
$1\frac{1}{16}$ in.	4.6	1.33

3. *Corliss Cylinder Boring Machine.* This tool was driven by a 10 H. P. C. and C. motor and was boring the brass boxes, $6\frac{1}{4}$ in. diameter, of the main shaft bearing of a large ice machine. The average current was 14.47 amperes, representing 4.17 H. P. at 215 volts.

In order to place the results in a more convenient form the following table of average powers was compiled.

TESTS AT THE CROCKER-WHEELER FACTORY.

No. of Test.	Size of Motor.	Number of tools driven by motor.	Average Amperes.	Average horse power.	Remarks.
1	1.5 H. P.	1 boring machine.	8.3	1.23	
2	1. "	1 drill press.	2.85	.42	Less than ½ full load of motor.
3	1. "	1 " "	2.86	.42	
4	1. "	1 " "	1.9	.28	
5	1. "	1 punch press.	4.86	.71	
6	1. "	1 gang drill.	4.75	.7	Drilling ¼ in. and ⅜ in. holes.
7	3. "	2 machines.	10.04	1.48	
8	1. "	6 "	5.86	.86	All small machines.
9	3. "	7 "	13.36	1.97	
10	3. "	8 "	9.92	1.46	
11	7.5 "	2 "	33.1	4.87	Required 2.3 H. P. to run shafting only.
12	10. "	20 "		4.78	Tested by wattmeter.
13	3. "	5 "	7.0	1.03	
14	3. "	1 engine lathe.	11.4	1.68	Light cut taken by tool.

TESTS AT THE DE LA VERGNE WORKS.

1	15. H. P.	1 planer.	20.08	5.11	Planer 10 ft. x 9 ft. x 22 ft. Voltage 190. ⅝ in. drill.
2	5. "	1 drill press.	4.07	1.23	Voltage 215.
3	10. "	1 boring tool.	14.47	4.17	Voltage 215.

The results obtained in these tests show that the power required to drive machine tools has been considerably overestimated, for it will be noted that with a large majority of the tools tested, the motor was not more than one-half loaded, and in

these cases it was seldom that the load equalled the full power of the motor, even for an instant. In the case of the large planer, although the motor was overloaded 50 per cent. upon reversal of the bed, the average load was only one-third of the rated full load. With this machine, however, when the piece of work is very short, necessitating more rapid reversals, the average load will be much nearer the most economical output of the motor.

The question of running machine tools by individual motors or grouping a number of machines together and driving them by one motor, does not seem to allow of a general solution. It would not be advisable, for example, to use the individual system where there are a number of small tools, each one of which requires only a small fraction of a horse-power. On the other hand if we have a large tool that requires considerable power, it would seem to be far more economical to run it by a single motor, using as little belting and shafting as possible.

Many of the manufacturers of machinery are now supplying boring mills, punching presses, drill presses and other machine tools arranged to be driven by electric motors. In most cases all that is necessary is a shelf or bracket on the tool to support the motor, and a gear wheel in place of the main pulley, unless a belt connection is preferable. A press or other tool having a large fly-wheel may be driven very conveniently by cutting teeth on the edge of the wheel which gear with a pinion on the motor shaft.

Electric Power in the New England Cotton Mills.

The introduction of the electric system of distribution of power in the cotton industries of New England is now fairly begun. Although there are no large mills driven entirely by this system, a number of them have an electric plant and certain sections of the mill are driven by motors. An electric plant was installed four or five years ago in the works of the Silver Spring Bleaching and Dyeing Co., at Providence, R. I., but it was intended chiefly for lighting. But motors were placed in the carpenter and repair shops, and several other places, until at present there are about 100 H. P. of motors installed in eight units. The generating plant consists of three 100 H. P. U. S. dynamos belted together from a countershaft which is driven by a Corliss engine. Two of the machines are 110-volt dynamos which are used for lighting and running most of the motors at present. The third machine which has just been installed is a 500-volt Westinghouse power

generator of the same type as the lighting machines. There is only one machine at present connected to the 500-volt circuit, a 30 H. P. motor which drives a centrifugal pump supplying a storage reservoir with water for use in the bleacheries. The electric plant in this mill is not of much importance yet, but its chances for development are very bright since there are a number of machines now run by individual steam engines. These could be most advantageously replaced by electric motors as they are in some cases a great distance from the boilers, involving large losses from condensation.

A visit was made to the works of the Dunnell Manufacturing Company, at Pawtucket, R. I., where a very fine electric plant has very recently been installed to drive the calico printing machines. The problem of running this class of machinery by electric motors has been a very difficult one to solve, for the motor must be capable of running at a number of different speeds, and running constantly at any given speed with a variable load. In this case it has been solved by the use of a modification of the Leonard system of motor regulation. The outfit for each printing machine consists of a motor and a dynamo of the same size, the field rheostat of the dynamo being placed alongside the printing machine. The speed of the motor is thus changed by varying the voltage of the particular dynamo which supplies it with current.

The dynamo room contains eleven dynamos of the new moderate speed, four-pole type, made by the General Electric Company. They are run by a Corliss engine through a system of belting and ceiling countershafting. Six of these are 20 K. W. machines and four are 25 K. W. The eleventh dynamo is a similar 20 K. W. machine used for exciting the fields of the other dynamos. The normal potential is 250 volts, and is lowered in any particular dynamo when slower speed of the motor connected to that circuit is desired. This plant has been completed but a short time, and it was not possible to obtain any accurate figures showing the power used by the motors under various conditions of speed and load. Formerly the machines were run by individual engines and much difficulty was experienced in starting them, as the pressure of the printing rolls against the cloth is so great. With electric motors this difficulty is overcome, as the motors will stand a very heavy overload for a short time, and the starting torque is very great. The great advantage of the electric system as here used, is not so much in the saving of power as in the convenience to the workmen, and hence the increased production.

The saving of power, however, is quite considerable as in the old system steam was piped several hundred feet to the small individual engines, which were necessarily inefficient under the best conditions, and added to this the engines were run part of the time with partly closed throttle, still further decreasing the efficiency. With the present system, the attendant at the machine may quickly vary the speed to any required extent by turning the rheostat near the machine.

Although this plant has been in operation only a short time, it is claimed by those in control that the production is materially increased. In a paper by Mr. S. B. Paine in *Power*, June, 1895 he states that the increase in the production amounted to more than 25 per cent., and that the quantity of "seconds" (inferior product) was also considerably reduced.

This is very important, as the men in charge of printing machines are skilled workmen of the higher order, and a small saving in wages for a given production is of more value than a considerable saving of power.

A visit to Baltic and Taftville was also made to see the practical working of the well-known power transmission plant between these places. At Taftville, where the Ponemah mills are located, there is not sufficient water power to drive all the machinery, so an electric plant was installed at Baltic, 4½ miles up the river where a dam had been built, giving an available head of 34 feet. The wheels are horizontal balanced turbines, two of them being rated at 800 H. P. each, while the third one is rated at 300 H. P. The wheels are belted to a long line shaft, which is in turn belted to the dynamos. The generators, of which there are two, are placed in a separate room. They are of the three-phase General Electric type and are capable of supplying 250 K. W. at 2,400 volts. They have ten poles and run at 600 R. P. M., giving a frequency of 50 cycles per second. The field is excited by a 3 K. W. bipolar dynamo belted from the generator shaft. The power is transmitted to Taftville by a very well constructed pole line. The motors are located in the basement of the Ponemah mill near the engines which they replace. They are belted to pulleys which are connected to their respective shafts by friction clutches in order to enable the motors to be started without load, as they are of the synchronous type. The motors are identical with the dynamos except in having an induction winding of heavy bars sunk in the pole-pieces, to cause them to be self-starting. In starting the

motors, the switch in the induction circuit is closed and then the line is connected to the armature, causing it to start as an induction motor, without a very great torque, however. When the motor has nearly reached full speed, the field is excited and it will speed up until it falls into step and then the induction switch is opened. This method of starting has two advantages: first, no auxiliary motor is needed; second, no device is required to tell when the motor is in synchronism with the generator.

One of these motors drives 1,200 looms requiring an expenditure of about 155 H. P. The other drives 500 looms and also the railway generators for the Norwich Electric Railway Co. The introduction of this plant has enabled the company to concentrate all its power for use in one mill, tending to decrease the cost of production, diminishing transportation charges and avoiding the use of any coal for steam power.

Conclusions.

First Cost.—Practically the only objection which can be urged against the electric system is the fact that the first cost of installation is greater than with ordinary belting and shafting, but even this is questionable, since the authors know of cases in which the estimated total cost of installing the necessary belting and shafting was actually greater than the equivalent electric motor outfit. The electric system would be cheaper for example in the case of very long or scattered buildings or those containing many stories or rooms, in any of which cases the belting and shafting required would be very complicated and expensive. The use of belting and shafting requires a much stronger and more expensive roof or ceiling than the electric system.

Saving of Power.—It might seem that the electric system would actually consume more power than the ordinary plan since it involves two transformations of energy. In most cases, however, if the power has to be distributed to a number of machines, particularly if they are located at any distance from the engine, the loss of power is less with electric transmission. This is explained by the high efficiency of the dynamo and motor, compared with the low efficiency of belt transmission as ordinarily practiced, involving as it often does very imperfect alignment and lubrication of the shafting. Perhaps the greatest saving, however, of the electric system is due to the fact that the consumption of energy entirely ceases when the tool stops. This

stoppage in the case of the busiest tools, amounts to at least 25 per cent. of the nominal working hours throughout the year, and with large or special tools which are not used so steadily, the stoppage is often as high as 50 to 75 per cent., since there are many whole days when they are not used at all.

Idleness due to strikes as well as to slack times must also be considered, and would usually amount to quite a large percentage in ten years for example. This assumes, of course, that a portion of the shop is running, which is usually the case even under such conditions. In short, with the mechanical system there is an enormous amount of shafting, idle pulleys and belting which run for long periods of time doing little or no useful work, but consuming considerable power.

Wherever electric motors can be substituted for a number of small engines scattered about, the saving in power is very great not only because of the low efficiency of small steam engines, but also by the avoidance of condensation in long steam pipes.

Increased Output.—This is, perhaps, the most important advantage gained by the electric system, since after all the cost of power is a very small item, being, according to Mr. Richmond,[1] only about 1 per cent. of the wages paid in average machine shop practice.

This increased output is secured by the greater convenience and promptness in starting and stopping as well as in regulating the speed of the machinery. The workman can, for example, temporarily increase the speed when the conditions are favorable, thereby saving considerable time.

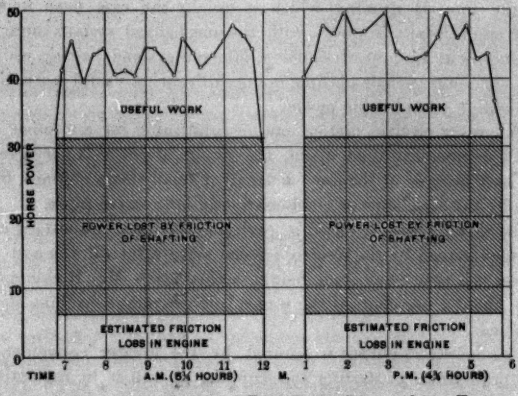
Flexibility. The great convenience of moving the tools and placing them in any desired position is another special advantage of the new system. The great adaptability of this system is particularly well shown in the case of a factory which was almost completely destroyed by fire, nevertheless a few uninjured tools in a remote end of the building were operated successfully by means of electric motors within two days after the fire.

Speed Regulation.—The ordinary type of motor used in factories is the plain shunt wound machine, fed with constant potential current. The motor is started and varied in speed by means of a rheostat in the armature circuit. This simple arrangement answers very well in most cases, but for variable speed between

1. *Engineering Magazine*, January, 1895.

wide limits, a series wound motor controlled by a rheostat as in electric railway practice may be preferable. In other cases some special method of regulation such as the Leonard system, or the "boost and retard" plan may be adopted.

In concluding, the authors wish to express their sincerest thanks to the various companies for the courtesy shown by them and for the kind assistance which they rendered during the tests.



Comparison between Useful and Total Power Consumed in a Factory, Observations taken every Fifteen Minutes.

Bibliography.

The most important papers on this subject which have appeared up to date include:

"Electricity in Mill Work," by C. S. Hussey, read before the N. E. Cotton Manuf. Association, April 29, 1891.

"Electric Machine Tools," by S. S. Wheeler, *Electrical Engineer*, April 12. 1893.

"Development of Electric Machine Tools," by S. S. Wheeler, *Electrical Engineer*, Oct. 4, 1893.

"Power Losses in Transmission Machinery," by Wm. S. Aldrich, *American Society of Mechanical Engineers*, June, 1894.

"Electric Power in Factories," by T. Richardson, *Electrician*, London, Oct. 19, 1894.

"Electricity in the Iron and Steel Industry," by D. Shelby Biggs, *Engineering Magazine*. December, 1894.

"Electric Power in Factories," by G. Richmond, *Engineering Magazine*, January, 1895.

"Direct Electric Driven Machines," by W. E. Hall, *Cassier's Magazine*, February, 1895.

"Electricity in Textile Manufacturing," by Dr. Louis Bell, *Cassier's Magazine*, February, 1895.

A paper by S. B. Paine, read before the N. E. Cotton Manuf. Association, appears in *Power*, June, 1895.

DISCUSSION.

THE PRESIDENT:—I think that Dr. Crocker's apology for presenting exact data is not necessary, as that is precisely what we want. Opinions are valuable, more or less, according to the persons they come from. Exact data is always valuable, and in a new departure of this kind it is especially useful to us, and the data given here is certainly of great value to any one who is connected with machine work. The paper is open for discussion.

DR. C. E. EMERY:—This paper is of great value. Without question the electric motor should play an important part in shop transmission. The extreme view originally expressed that a motor should be applied to every tool, is modified by the illustrations here presented, though unquestionably there are many tools which should be thus driven independently. For tools that are used occasionally it is wasteful to keep a belt running, particularly in an out-of-the-way corner where a long line of shafting must also be kept in motion. An electric motor is desirable in such case as well as to operate tools which are at times used during the night. There are also many tools of which the speed is required to be changed frequently, which can be most economically and most satisfactorily operated by an electric motor. There are, however, advantages in having some of the tools grouped together, for the reason stated in the paper, that the power required for the group is much less than the sum of the powers required to operate each separately. Properly arranged groups therefore require a less number of motors, and motors of less aggregate power, and moreover the larger motors are proportionably cheaper so that a considerable saving of interest is secured to balance the comparatively small losses due to running short countershafts. These considerations are not arguments against the desirability, of using independent motors on certain tools, but show the necessity in this, as well as in all branches of engineering work of considering the conditions for each particular case.

The electric method of transmission has become of great importance in the distribution of small powers in our large cities. In the lower part of New York it is very common to have warerooms and small shops in the same loft. With the old system long shafts were run underground and through various buildings with belts leading in all directions, and in many such shops the rattle of the machinery could be distinctly heard. Now, in many such places, small motors are substituted requiring little care, and

the noise is so far decreased that it is hard to realize that manufacturing is being conducted in the same room. The facilities for working overtime are very greatly increased, as it is no longer necessary to make charges for keeping long lines of shafting in operation and, indeed, when the current is taken from the street, service is on tap all the time and the expense ceases when the work is stopped. Such a power transmission practically makes whole blocks of buildings part of a large manufactory, and the advantages of the system are equally applicable in regular shop practice. We are particularly to be congratulated in having the facts stated in relation to the different methods of installation, and the same will prove very valuable in laying out future plants. I feel very grateful to the authors of the paper for the clear presentation they have given us of the subject, and particularly for the very valuable facts they have presented.

MR. H. WARD LEONARD:— I have some familiarity with the plant that the authors have mentioned, that has been installed at the works of Dunnell and Co., at Pawtucket, R. I., and as it is a pretty good sample of the superiority of the electric motor over steam engines for practice of that kind, it may be interesting to give the facts in connection with that case. These presses for calico printing are quite large affairs. They take about 30 H. P., and formerly there was a throttling engine connected with the press, and by operating the throttle the speed of the press was regulated by the operator, for each particular press. The torque of the engine was not sufficient to enable them to start the press up from rest except by the aid of a pinch bar, which was used by the operator to add to the torque. The presses have a large number of rolls which are arranged in a circular frame and these are set down by pressure upon a blanket sort of an affair, so that the pressure upon the rolls and the number of rolls set down will determine the torque. The electric motors that were put in there at first were of the plain shunt-wound type, with a rheostat in the armature circuit. I think it may be well to point out the conditions with a shunt-wound motor and a rheostat in the armature circuit. Suppose that we have the armature so running that it is at one-tenth its full speed, so that about nine-tenths of the total voltage of the line is dropped upon the rheostat and one-tenth is upon the terminals of the armature. If now, under those conditions, the torque and consequently the current be increased 10 per cent., the entire drop of voltage will be upon the terminals of the rheostat, and the motor will come to rest. Therefore any slight variation in torque in a motor controlled by a rheostat at slow speeds makes its movements extremely erratic, and it is impossible to obtain any kind of satisfactory results. In a case like this printing press, where the torque was quite variable as the press went around, due to variations in the thickness of the blanket, etc., that method of operation was not a success, and they then used the plain series-wound motor, and with the same

difficulties, and even more marked. Then a commutated field motor was employed, and finally a very strongly accumulatively-wound compound machine was used, and none of the results were satisfactory, and I made an application of my method of exciting the motor field constantly, and then varying the strength of the generator field, which is also separately excited, and we were able to get perfect control of the speed and practically unlimited torque. We were able to start without any difficulty—without any outside assistance, and one point which was rather impressive to the steam engineer present—the Westinghouse-Church-Kerr Company were the parties who were putting in the steam plant—and Mr. Church was there. When I succeeded in operating the press satisfactorily, operating it at variable speeds, and he saw the very enormous torque which the motor was developing in starting, he stated that while I seemed to be able to get the press going, he had no such surplus power in his engines as would permit of such a very large load being suddenly thrown upon them; and when I explained that while the torque was very large, yet the energy was quite small really, on account of the low voltage employed in starting; he said that he would not attempt to discuss the subject theoretically, but that as he had an indicator on his engine at that time, that he would take diagrams if I would start the press up at its slowest speed half-a-dozen times, and he would find out how much power was indicated. So the press being about 600 feet across the yard from the engine house, we set our watches together and at a certain time I started the press about half-a-dozen times or more, and he kept the pencil down on the diagram taking the card. Then we waited, and in the course of half-an-hour word came over to us to ask why we had not started up. The fact was that he had an engine running at about 75 H. P., and the additional power of starting the press was so trifling that he thought it was just the usual slight variations of the cut-off of the engine and did not think the press had been started at all. That shows the amount of starting power that would be required in such a case as that. Last July I saw the original press that I put into operation about three years and a half ago. The generator was a regular old bi-polar Edison machine of about 25 K. W. with an exactly similar motor, and it had been running in regular service for about three years and had copper brushes on the generator, which I was rather surprised at, as I thought they would probably have changed them to carbon before that time. But there was no evidence of wear upon the commutator, or sparking, and the result, according to the operators of the press, was quite satisfactory.

Another application that I think of in connection with machine driven tools, which some of the members of the INSTITUTE saw, and has been used considerably by William Sellers and Co., is in connection with large boring machines for boring, drilling and tapping the heads of boilers and things of that nature, where it is

desirable to secure a large number of different automatic speeds and a reversible motion. But my method of control is only applicable, on account of complication of wiring and first cost, in instances where very great variation of speed and a large number of automatic speeds are required, or where the units are so large that rheostat control becomes impossible to manipulate or prohibitive in expense.

MR. GANO S. DUNN:—The figures given by Dr. Crocker, of a loss of approximately 80 per cent. of the power of the engine to drive the shafting idle are astonishing, and when the Crocker-Wheeler Electric Company first took up the question of motor driven factories this statement was challenged very generally by the authorities to whom it was made. They brought figures to show that even when three or four intermediate sets of shafting were used, the loss in the journals and belts for a given power delivered, could not aggregate such an amount; and it did seem to us at the time that there was something unexplained. Dr. Crocker's paper points out the cause, and I believe is the first paper to show it clearly. It is the fact that the tools are in actual operation for but a small portion of the total time. I do not doubt that if every tool were in operation all the time under full load, the efficiency of shafting distribution would be very much higher than the figures he gave. The figure of 75 per cent. friction loss is not a high one. We have equipped factories where it has been up to 85 per cent., and 75 per cent. can be considered as a good average condition. In the new works of the Crocker-Wheeler Company, much care is being taken to get the advantage of all points learned in our dealings with other factories, and we hope to have an illustration of the very best and most modern method of driving a shop. The wiring is to be down under the floor and to come up at each machine or group of machines where it is needed. The arrangement of circuits is such, that for occasional night or special work a very small generator can be put on and run one or two tools, and those tools may be located at any part of the factory. We hope to be able to show shortly what may be considered as standard practice for a motor system of distribution, and one which will be a precedent for some years to come.

MR. GEO. W. BLODGETT:—I had occasion a few months ago to look up the subject of driving machine tools by electrical motors, and I visited several places where that method of running machinery was in use, and it may be of interest to the members if I recite some of the facts which I learned. The Morris Safe Co., in Readville, Mass., are driving their works by electric power altogether, using a steam engine and a generator of 500 volts, I believe—80 H. P., at any rate—which drives eight motors in different parts of the shop, varying in capacity from 10 to 25 H. P., each motor being connected with a section of shafting from 30 to 50 feet long, and driving a group of tools. Their work is

the manufacture of fire-proof safes, and they make use of machinery for doing almost the whole of the work, and all the machinery in the shops is driven by electric motors. The shop where most of the cleaning and polishing is done, by means of emery wheels, is a very difficult place to operate a motor, on account of the fine dust of the emery and steel with which the air is filled and which of necessity gets into the commutator and under the brushes to a certain extent. However, with the exception of a slight sparking, which would be considered under other circumstances a rather abnormal sparking—no difficulty is experenced—and the motor which I saw in this shop had been running for several months with no change of brushes or commutator, and only showed a reasonable amount of wear, certainly nothing dangerous. This concern formerly operated by belting and shafting alone another shop where they were running about the same number of tools and doing the same kind of work, and they estimate a saving of 20 per cent. to 25 per cent. in the amount of coal used now over what it was when they ran entirely by belting and shafting.

I visited also a concern in Worcester, Mass.—the Rice, Barton and Fales Company, manufacturers of general machinery, largely for paper mills. They use several motors of which three are on an electric crane, one for moving the crane to and fro the length of the shop, another for moving the hoist transversely, and the third for raising and lowering weights. It works with perfect satisfaction and is much more convenient, takes much less power, and there is much less weight than with a steam engine for which the crane was first designed.

The Kent and Stanley Company, of Providence, R. I., have just erected a large seven story building covering more than an acre of ground, which is operated entirely by electric motors. The machinery in the building was not all in operation when I was there, but was being fitted up, and is used principally for the manufacture of jewelry; the different floors or different parts of floors being let to manufacturing concerns which do this kind of work, some of one sort and some of another. The power was at that moment being derived from the Narragansett Electric Light Company, but dynamos and engines were being installed in the basement of the building for driving motors for the machinery on the different floors. Here the motors are usually placed on a platform suspended from the ceiling, high enough to clear the heads of people and the work which was being done on the floor, usually, I should say, at a height of eight or ten feet above the floor, and were connected by a belt to a shaft running lengthwise or crosswise of the room, and driving groups of machines. I was struck here with the saving of valuable space, and particularly with the enormous saving over what would have been required for transmitting in the old way the power from the basement to the top of the seven story building and around in differ-

ent places on the several floors of the building. The arrangement of shafting and pulleys to do that work would have been extremely complicated.

I have myself recently installed an electric motor for driving a transfer table in some railroad shops, the table being a little over 65 feet long, weighing 78,000 lbs., and adapted to transfer a locomotive which weighs 204,000 lbs., making the total weight of the table and its heaviest load more than 280,000 lbs. It runs upon two rails in a pit, and the power is applied by a shaft running the length of the table and connected to wheels at each end which run upon these rails. In the first starting of the table, owing to a fault in its construction, a part of the iron work rested upon the rails, and the weight did not come upon the wheels but upon these iron pieces which supported a part of the weight of the table. A 25 H. P. nominal "G. E. 800" motor was used, and we put on at a voltage of 450, more than 100 amperes without starting the table at first, although we were able to slip the wheels on the rails without moving the table until the difficulty was found and remedied. Now it takes 15 to 25 amperes at 450 volts to run the table, and it works much more smoothly than it formerly did. It has only been in operation a few weeks and will doubtless act better when it has been a longer time in service.

Mr. C. R. VAN TRUMP:—The engineer who has to do with generating and furnishing motor power is, indeed, indebted for the figures that are given in this able paper. It gives us a clue that we certainly have not had before, and brings out some very important points. Electricity from a central station certainly appears expensive to the ordinary manufacturer who intends to run his shop with it. It is expensive because it all comes in a lump, in one bill, where in the case of steam power or other motive power, he has his labor and his coal and other expenses, repairs, that come in one by one, and he does not know how much his power does cost him. In the case of electricity, however, he gets his bill once a month from the central station, and it seems very large indeed. I have had some experience quite lately in this very line, and will mention one case only, of a small printing shop that was complaining very strenuously about the cost of electric power, and, in testing the matter out, we found that it cost them about 15 cents an hour to run the shop with nothing on. At 10 cents per K. W. hour his largest press consumed about nine cents an hour, and it was run very little indeed. His next largest press cost him about five cents an hour to run, and the others about two, of which he had three. He did not run more than two or three presses at a time, and never the large one when he ran the others, so that his frictional losses were certainly quite extensive to him.

MR. HARRY ALEXANDER:—Having recently had occasion to demonstrate some of the facts mentioned in this valuable paper it might be well to speak of the circumstances. In fact just be-

fore I left we made some tests in a certain business house in New York that runs machines for manufacturing purposes, having about 25 H. P. (I believe a) Whitehall Corliss engine to do the work; we were trying to displace this engine by a motor. They did not feel free to do so until we made a test. The card of the engine taken at the time by the engineer of the company, showed 22 H. P. with 179 lbs. of coal. The steam was carried about 80 feet. We took a 20 K. W. dynamo, coupled it to exactly the same shafting, the conditions being exactly alike, the coal being shoveled directly from a scale. The figures showed, with the same amount of machines going, the same work being done, 140 amperes, which is about 20 H. P., counting about 800 watts to the horse-power, at 92 per cent. efficiency. The saving of coal at that time was 100 lbs. for the same period, the coal being 80 lbs. against 179 lbs., the card on the engine showing 22 H. P., while, as I said, at 800 watts per H. P. the motor showed about 20. After that test was made, we installed a motor in the laundry down-stairs, a five H. P. motor, running, I believe, ten hours. The motor, when all the ironers were at work, consumed an average of 34 amperes. At that time we decided to run the ironers in pairs, as they usually were run, but instead of transmitting the power through a counter-shaft, decided to couple a one H. P. motor to each pair of ironers. After that was done, although temporarily, the counter-shaft not being removed and the motor merely placed between the two ironers, our current consumption for exactly the same work done was a little less than 20 amperes, or four amperes per machine, there being five one H. P. motors to operate each pair of ironers; and in view of these circumstances I should say that this alone showed the house the advantages over the transmission of power through belting. I have not quite concluded the test, as things were not in shape at the time I left for me to give any further exact figures, but under the circumstances, especially in the laundry, I dare say that the figures will show that the independent motor under certain conditions is very efficient indeed. And as to the 35 H. P. motor that we installed up-stairs, on the strength of this test, we have decided, instead of the one 25 H. P. motor, to run the floor above, which is principally operated by an engine now, to lay it out in four wings, operating each wing by an independent motor of about five to seven or seven and one-half horse-power each.

DR. S. S. WHEELER:—A large portion of the electric factory equipments are decided upon, because of the flexibility and convenience of the system, and therefore I think that this feature deserves a little more emphasis than it has received in Dr. Crocker's paper. There are very few electric power plants put into factories simply because it is the ideal or the most perfect system. I think the prevailing rule is that the manufacturer waits until he finds that he can go no further in the development of his factory with his shafting, and is forced into some

other means of securing power. The use of wires of course enables the manufacturer to carry the power to remote points on his property much more easily and quickly than he could carry it by shafting, and that is particularly true when any alterations or additions are to be made. I know of several instances on hand at present, where the owners of factories have decided to go to the small increased expense of electric power, because they wanted to tear down a part of their buildings, and by adopting an electric system they could continue the power in the remote parts that were not being torn down, while the intervening buildings were removed. By the use of electric service they could string their wires across the spaces and fill the factory up until they came to the limit of their engine capacity. And then we have been called in to introduce electric power in place of shafting as a means of reducing the load on the engine, so they could continue their manufacturing. In other cases we have put in electrically driven machinery, so that part of a factory might be driven from a city circuit, while they were rebuilding the engine room. In our own work we had a large 50-inch lathe in a building which was completely destroyed by fire. That lathe was in operation within two or three days after the fire, right out in a field, driven by a small pole line from the engine room, and with a small canvas tent over it to keep the rain and brick dust off while the re-building was going on. That lathe has, owing to the pressure of our work, been in continuous use day and night from two or three days after the fire until now, when the new buildings are completed over it. That, of course, would not have been possible if it had been a shaft driven tool, but as an electric tool we could keep it running all the time. In the same way we have been able to shift other tools around on roller trucks and in all sorts of ways to various parts of the shop, and put wooden sheds over them, and keep them going, and when the building came to the point where they stood, we would take them up and roll them along 20 or 30 feet further, get them out of the way and keep them running.

Capt. Wm. Brophy:—In his conclusions, the author of this paper has omitted one very important factor in favor of the electric motor. Every man in business finds it necessary to insure his property against loss by fire. We all know that the small boilers and small engines placed in basements or in attics have been a fruitful source of fire. If the fire starts in the basement, it spreads rapidly through the upper portions of the building. If the boiler and engine is located in the attic, or upper story, the entire building and the goods contained therein are injured by water, entailing a very heavy loss on insurance companies. I regret to say that there are some insurance associations still so benighted that they cannot appreciate this fact, but most of them do. All of them will yet emerge from the wilderness and realize that the electric motor is a great benefactor to them in their

business. There have been a few cases of fire, as I must admit, that have been traced to electric motors, but it is due to the carelessness of those who install them, or of those who have them in charge. But there is no reason why an electric motor should be more hazardous as a fire risk than a refrigerator.

MR. OBERLIN SMITH:—I read yesterday in a local paper here that Niagara Falls was the "electric city," but probably not being fully developed, they have not yet got electric bells into my room, nor any other electric waking-up arrangement. Some of my most highly charged electric friends here stored me so fully, a good while after midnight, with valuable high-potential knowledge, that I didn't get switched on to the breakfast circuit very early this morning, and so I didn't hear all of this valuable paper. I cannot talk about it as clearly as I would like to, through thus being a little late, but next time we come, the city will doubtless have become more electric, and all these things will have adjusted themselves.

From the point of view of a mechanical engineer more especially, I want to say that with those of us who have thought most and seen most of the subject, there is no question any longer but that we want to drive our tools with motors. I do not think we need any more discuss whether we shall or shall not, as we did perhaps a year or two years ago. We were then feeling our way. Following the wonderfully rapid strides in electrical development, we have now gotten to a place where we need not ask the main question. We want to use them as a matter of course. It is only a question of time when they will be in all our machine-shops and in all other mills, even cotton mills and such places where the power required is very constant, where really we do not need them as badly as we do in the machine-shops and other places where the power is extremely inconstant. What we want to discuss, and what we are discussing here, is merely methods and kinds of apparatus. My experience has not been as great yet as I would wish, although that is a matter the future can remedy. As far as it goes, it has been chiefly with punching and cutting presses and I can say that, so far, the behavior of motors under such circumstances has been admirable; and we cannot expect a motor to act as well in intermittently acting machines of this kind, as we can with a lathe, or even a planer. Drill-presses, lathes and milling machines, where a constant torque is usually required, at any rate for a few minutes at a time, are much easier on a motor, than is a press where the power required for running a loose flywheel for a while is almost nothing, and where the torque is then increased instantly for only a fraction of a second, perhaps 1,000 or even 5,000 per cent., then going right down again. All this is well taken care of, however, with a heavy flywheel and with the peculiar adaptation of a motor for such work. In running press flywheels light, a little object lesson has, I think, been gained in calling the attention of people who use

such machines to the considerable power that is being wasted in ordinary shafting journals. Most of us would hardly realize it till we tried it, and probably with nothing but the old fashioned dynamometer we might never have taken the trouble to bother with a flywheel running loose on a stationary shaft. I was somewhat surprised myself to see that from one-half to one horse-power was required for the ordinary press flywheel, medium size, weighing, say, from six to twelve hundred, or something of that sort. The journal friction in such cases has a coefficient of perhaps 15 or 20 per cent., with cast-iron running or forged steel, under ordinary conditions. When, therefore, you watch an ammeter and see that it registers 700 or 800 watts with a mere loose flywheel running around, you can very well realize what the waste of power must be with a mass of shafting and countershafting and idlers of all kinds, and tight belts bending over the shafts out of line. This increased facility of observation is an incidental advantage which the motor will be to us, and makes an ammeter a very pretty thing from which to read the power used at any moment by the machine being driven. We then have a simple and glorified form of dynamometer, so to speak, such as we never would otherwise have used.

A motor is sometimes a good thing for such work as driving presses in time of breakdowns. I had recently an experience that showed the advantage of such driving instead of having a mass of transmission machinery attached to the press with a tight belt. I was testing a press that would give about 50 tons pressure for punching iron with holes one inch in diameter. A number of pieces were brought from the smith-shop, of different thicknesses, and everything worked all right until one was put in which looked like rusty iron, and which the blacksmith sent in from the iron pile, assuring us it was a "piece of iron," like the rest, but which happened to be unannealed tool-steel. It was far beyond the capacity of the press to punch such a piece of metal, and something had to give. The die was mounted upon a cheap "bolster," which very properly cracked so that the stress did not break the machine itself; but the motor behaved admirably. The fuse went off with a "fourth-of-July" sizz, and the motor slackened itself right down so that everything stood still without any damage at all; whereas if we had been connected with the whole plant of an ordinary machine shop, I don't know what would have happened.

A little point mentioned by Mr. Dunn is, I think, a valuable one in equipping motors, where he spoke of the wires all coming from underneath. In the factory he referred to, I believe formerly a good many of them came from overhead, and that was my one criticism of what was otherwise an admirable system. One of the great advantages we have in driving individual machines with motors is the getting an entirely clear room, and I never could see any possible objection to bringing the wires from under

the floor. We then get the ideal condition for a shop. Aside from the advantage of more unobstructed light in general, and the chance for using sky-lights if we have them, and the light from our windows, by getting rid of all overhead machinery and rigging, we have one very important thing that has not been enough dwelt upon, and that is head-room for our future electric cranes. I do not mean the crane we now build. The crane industry has gone only a little way, although there has been a good deal of it; but I do not think any of us rightly conceive of the great convenience and rapidity of work that is coming from the handling of our small loads by this means, with the light overhead crane that is yet to come, driven by electricity, running everywhere, raising anywhere from 50 pounds to a ton. When we get this ideal system of driving—one that is becoming real, too, especially in the shop mentioned by Dr. Wheeler and Mr. Dunn, and some other shops, with everything connected from the floor and nothing overhead, we shall have our present type of ordinary travel, ing cranes over our heavier conventional tools, over our lathes-planers and drills. Now we limit them to erecting floor use, and do not think of putting them over our common lathes and planers. Each of these now require the work to be lifted in by hand or by some special crane of its own, generally a hand crane. We can also have little electric cranes in special cases running from certain tools over to other tools and individual cranes upon as many as we please. Of course those cranes will be cheapened as the system develops, and there will be an enormous saving in the handling of work. Now, for anything but very light work which the men can pick up and put right in the machine, there is a considerable waste of time putting work in and out of machines—more than any one would realize, and often amounting to more than that required for the actual cutting. All this is going to be one of the direct results of the clear head-room brought about by the use of motors.

The system that has been talked about a good deal of grouping three or four or five machines to little pieces of shafting on the wall or ceiling, is a good one in certain cases, and during this tentative period no doubt has its proper place; but I do not think it has come to last, because we get the disadvantages to some extent of the old shafting system. As motors become better and cheaper, as they will, we can afford to have one for every tool and get the full advantage of individual driving. The problem talked much about until quite recently has been whether we should put in motors at all, because we did not know whether they were going to take more power or not. As remarked in the paper, that is a point of very little importance, compared with the total expenses of the shop. It doesn't matter if it is five or ten or twenty per cent, considering the great advantages we are going to get in all these other ways.

One feature that has been touched on might perhaps be

brought out a little more in detail, the balancing up of all power so that only the average need be represented. Taking the extreme case of a press, which is more intermittent in its action than almost any other machine perhaps. It stands quietly waiting for the work to be put in and adjusted, then is clutched in gear and the ram allowed to come down idly till it strikes the work, which is a comparatively long time; then the punch goes through the work in a very short time, then a rather long time is occupied for the punch to come up through the work, and for the ram rising the rest of the way and the machine coming to rest, removing the work and all that. Here we have a maximum of power exerted during an extremely small percentage of the time. The chances are that with a number of presses standing in a shop, the rams would never all happen to be doing their hardest work at the same instant. We therefore have our power averaged up pretty evenly most of the time. Not so, however, with shafting systems which must be prepared for maximum stresses.

The point mentioned by Dr. Wheeler, of arranging shops for growing afterward, is an important one. Even where, with good foresight, the shafting of a shop has been so planned, and the building so planned that they can be lengthened out indefinitely, or where it is arranged for other future lines, alongside and parallel to existing lines of shafting, a difficulty arises on account of the limited diameter of the shafts and pulleys and width of belts which could hardly be made high enough at first for a growth of 50 per cent. next year and another 50 per cent. the next, and so on. Now electrical machinery gives us a great flexibility for increase, which is a most important consideration.

Without going through the points of the paper carefully, but glancing (in reverse order) at the summing up thereof, we find that: The speed regulation Dr. Crocker speaks of is an important matter and very easily managed with an electric motor. There is an enormous waste of time in lathes, cutting off machines, etc., especially where the feeds are running radially, starting on a large diameter and feeding to the center. This can all be arranged by electricity so as to get a gradual increase of speed. The truth is that with the average lathe, which is the most important tool we have in our shops, the man running it is too lazy or too ignorant to change his speed as he might in making cuts radially across the face of the work. The result is he gets his speed four times or more too slow as he gets towards the center. The same is true in turning different diameters on a shaft where there are a number of diameters. It is usually too much trouble to change his belt, especially with a high ceiling. Shifting belts makes dirty and sometimes cut fingers, which he avoids if possible. The electric motor, with a little switch, gives one perfect control of all this.

Beside the actual high speed and the speed regulation which we get from the motor, in many cases just where and when it is

wanted, there is also the moral effect of having everything going lively. An electric shop is not going to be an old-fashioned shop, with everything crawling and creeping and waiting for something. The spirit of electricity is in the air and all this undoubtedly has a mental effect on the men and is going to spur everything up and make things run faster.

The motor system's flexibility, allowing the moving about of the tools at will, is a very good point of Dr. Crocker's. The capability of stopping a part of a shop and running the rest is also an important advantage—as, *e. g.*, during strikes, etc. Other occasions may require running part of the shop at night, instead of the whole of it, as in making overtime. In general, great benefits result from having complete control of all the different units of the shop, instead of having to link and fasten all together like a lot of convicts chained together by the legs. Neither men nor machines can work as well that way as they can with more individual action. The actual saving of power has been touched upon already, and I am inclined to believe there will in the end be a saving, in spite of the different transformations of energy between prime-mover and tool.

Regarding some other points not included in the summing up of the paper. One of these was mentioned by my friend here just now, (Capt. Brophy) namely, fire safety. Another one that has not been mentioned, I believe, is that when we introduce a current through a shop, either from our own local generator or from outside, produced from some big and especially economical cataract or steam engine, we have something that we want for other things beside power. We want it now for lighting, and also perhaps for welding, soldering, etc. We shall want it in future for heating, which I believe is destined to a great extent to be by electrical methods, although we know it costs too much just now. It has, however, so many incidental advantages that such heating is very likely one of the coming things. At any rate 'tis good to have our power in shape for a variety of functions instead of only for one purpose as we get it in our old belts and shafts.

The moral effect of an electric shop I have already referred to, and this is augmented by the greater amount of God's daylight you can get in connection with the gaining of the clear head-room before mentioned. This daylight is better not only by getting all our "rigging" away from overhead which now obstructs the greater part of the light, but because we can conveniently whitewash our shops or otherwise make them some light color which we cannot or do not do now. The average shop is so filled with shafting, hangers and belts that the overhead parts are sometimes whitewashed once in five years only, but sometimes not once in ten, because it is difficult to get all around it. The general healthfulness and cleanliness of this new era shop, avoiding the dust and surplus oil and old grease that comes from shafting, etc., thus enabling the shop to be kept looking more like a ball room,

comparatively speaking, is also going to help the men to do more work and going to pile up this moral effect I have spoken of.

We come now to the first item in Dr. Crocker's summing up, the cost of an electric plant. I fancy that the things I have been saying will be popular with electric men, because they want to see electricity go ahead, as do I also, from the standpoint of a mechanical engineer, but I am afraid I shall be unpopular if I say anything about motors costing too much. I tried it once or twice at various engineering meetings, and there was immediately a laugh or a weep, or something of the sort,—as much as to say that we poor ignorant mechanical men did not know anything about *that;* we had no idea of the enormous cost of these pieces of iron and copper and string put together, and we knew nothing about the way to put them together. There was a great mystery connected with electric motors and generators that we could not fathom, only by an extremely arduous course of electrical engineering. Whenever we would touch upon that ground, we were warned to keep quiet. But unless machine-shop men and cotton-mill men are prepared to pay the present price for motors, there is no use in talking electric power, and therefore I am going to say what I can say now better than I did before, because we are coming nearer to the time of cheap electric motors. They are cheaper now than they were. I find no fault with past and current prices, because they are perfectly legitimate, and are based in some degree upon the enormous amount of experimentation that has been necessary as a part of that dozen years of development which is one of the marvelous things in the history of this century. These splendid young men who mostly form our INSTITUTE OF ELECTRICAL ENGINEERS are going to continue that development. The old gray-heads hardly seem to "be in it" at all, if I may use such an expression. But this great industry that has come up like magic has cost enormously for the experimenting, for the litigation, and for the selling of a new product. All this has naturally gone into the cost of the motors and generators, besides the actual cost of making. The extra burden is, however, gradually disappearing, as things are getting down nearer to a standard, and the patient experimentation has given us these splendid motors with 90 to 95 per cent. efficiency—we do not need go much further in that line. But when we come to the mere mechanical construction of them, we all know that the material does not amount to a very large factor of the selling price. The labor is the problem.

The important economic question upon which mechanical engineers and electrical engineers should study together for the next few years is, when we have arrived at what we may consider the standard type of motor, how to make it cheap in regard to labor. This cheapness will come in the course of the evolution that has shown itself in manufacturing such things as sewing machines, and pistols, and bicycles, and typewriters. Such me-

thods are coming with the electric motor, and we shall learn to use more automatic machinery as well as to design the motors to suit it. This is largely a problem for the mechanical people, but they will doubtless rise to the occasion. This country is too brilliant in inventing tools and methods of work to ignore such a chance. Of course, important elements in making motors cheap are not only special tools, but the running through of large quantities in a "batch." This, I admit, is a difficult matter now. Factory men cannot at present prices buy enough motors to warrant electrical men making them up in large quantities; nor can these makers afford the equipment for cheapening until the demand increases vastly. Just as soon as we can make them in large enough quantities, 10,000 or 20,000 lots, all exactly alike, there is no question but that they can be made very much cheaper than now. All this will work itself out in time. The new era is coming, and just as soon as they do get cheap, we shall all be surprised at the immense number of them that will be used. I feel perfectly sure, as far as I am concerned, that they are going to be used as individual motors on every separate machine in very many cases. Not in all cases, but in a majority, probably.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 26th, 1895. President Duncan in the Chair.

SOME FEATURES OF ALTERNATING CURRENT SYSTEMS.

BY CHAS. PROTEUS STEINMETZ.

In the following I intend to review some of the work done in the last few years in exploring the actions and reactions of alternating currents. I shall endeavor to avoid as far as possible the use of mathematics, but I must beg you to believe that all the statements made are paralleled by exact mathematical calculations which have been partly published already, or which will be published in due time, but which if introduced in the present paper, would extend beyond the scope intended.

The practical applications of the modern alternating current system date from the introduction of the alternating current transformer. The possibility of transforming the voltage, and thus to use high voltage in the line and low voltage in the consumer circuit, gave the alternating current system a superiority not shared by the continuous current system, and thereby put the latter out of competition wherever great distance had to be traversed. A further advantage has been added in the last few years only, by the superiority of the alternating current motor over the continuous current motor, due to its greater reliability, better speed regulation and ability to stand overloads which made it preferable at least for high grade work.

It was not so in the beginning of the period of alternating current distribution. For a long time the system labored under the disadvantage of not being able to supply motive power, being available for lighting only. The inability to operate motors was the more serious as the alternating current system by its very nature is specially suited for long-distance transmission. In long-

distance transmission, however, the object aimed at is in general, at least partly, mechanical power. Thus the alternating current motor became the problem of those times. The alternating current generator, when running at synchronism in parallel with other generators, will keep on revolving even if the driving power is removed, and will operate as a "synchronous motor" keeping absolutely in step with the generator. Such synchronous motors are quite extensively used now, especially for large units. They have, however, the disadvantage that they are not self-starting, but must be brought up to synchronism before operating as reversed generators. Thus, either external starting devices had to be used or the synchronous motor made what is called "self-starting;" that is built so as to operate in starting and running below synchronism as a synchronous, or induction motor, or that variety of the latter which is called the "reaction motor." Thus, the

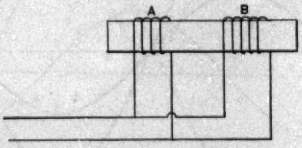


FIG. 1.

reversibility of the alternating current generator did not bring a complete the solution of the motor problem.

The solution of the alternating current motor problem had to be expected, either by the adaption of the continuous current motor to alternating current circuits, or by the discovery of an entirely new principle. The introduction of polyphase systems appeared to give the solution in the polyphase induction motor.

If by a system of E. M. F.'s displaced in phase from each other, currents displaced in phase are sent through the field circuits of a motor with short-circuited armature, rotation of the latter is produced.

This motor necessitates the use of polyphase systems, that is, systems comprising several circuits differing from each other in phase of their E. M. F.'s and currents. Such polyphase systems

require the subdivision of the single phase load, as lights, into and between several circuits, and require an approximately equal division to avoid on the one hand overloading of an individual circuit of a generator, while the generator as a whole is not yet fully loaded, and on the other hand to avoid the feature of "unbalancing" noticed in such systems. Since the different circuits of the polyphase system originate in the same generator, and the field excitation of an alternator has to be varied with the load, it is obvious that two circuits issuing from the same generator when loaded differently, will require different field excitations and thus at the same field excitations will show different voltages, the lesser loaded circuit, a higher voltage. The drop of voltage in the transmission and distribution lines being larger in the higher

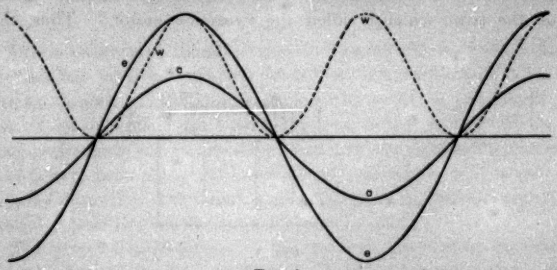


FIG. 2.

loaded circuit, will decrease the voltage of this circuit still more, and thus increase the unbalancing effect. Hence, even if the variation or potential at the generator terminals due to difference of load of the different phases should be small, it will be increased by the lines.

However, aside from this difficulty, the experience of the last few years seems to show that the complication of subdividing the circuits in the polyphase system is sufficient in most cases to exclude its use, and thus, comparatively little use has been made of the polyphase systems for light and power distribution. It has been different with long-distance transmission of large units, and power distribution, where polyphase systems have established themselves quite extensively.

Hence, the polyphase system did not completely solve the problem of alternating current light and power distribution,

and in returning to the single phase system, attempts were made to derive from the single phase system by "splitting of phase," a polyphase system for the operation of motors.

The futility of all attempts to derive a polyphase system from a single phase system, I have previously shown[1].

It is possible in a single phase system to resolve the E. M. F.'s into components in quadrature with each other or in any other phase relation. The insertion of a reactive coil into a lamp circuit produces two E. M. F.'s approximately in quadrature with each other and differing in phase with the main E. M. F., and by their combination any other phase differences can easily be produced. A condenser in series in the circuit, or an electrolytic cell will give phase displacement of E. M. F. also. But whenever E. M. F.'s displaced in phase are produced in this way, the cur-

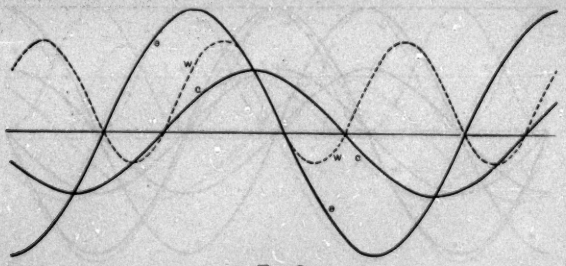


FIG. 3.

rents are in phase with each other or are insignificant.

Inversely, differences of phase of current can be produced in the single phase circuit. The current is an open magnetic circuit transformer at open secondary circuit, and the current in a transformer under full load, are practically in quadrature. Or still more, if on the same iron core two coils are wound and connected in parallel as shown in Fig. 1, the two currents in these coils can by changing the relative number of turns be made to have any phase difference from zero to 180°, but the E. M. F.'s are in phase. All attempts to use such phase differences produced in the single phase circuit for the operation of polyphase motors signally failed. While it is possible to operate motors in

1. TRANSACTIONS, 1892, vol. ix, p. 91.

this way, and this is being done to a certain extent, the current required is far in excess of the torque produced thereby. Such circuits of displaced phase lose their phase displacement as soon as work is required from them. The cause is that phase displacement of current, and phase displacement of E. M. F. cannot be produced simultaneously in a single phase circuit. This is a consequence of the law of conservation of energy.

In a continuous current circuit, current, E. M. F., and thus the power as their product are constant.

In a single phase alternating current circuit, the E. M. F. alternates, passing through zero twice per period. The current produced thereby alternates also, passing through zero either at the same moment with the E. M. F., in a non-inductive circuit, or at a different moment.

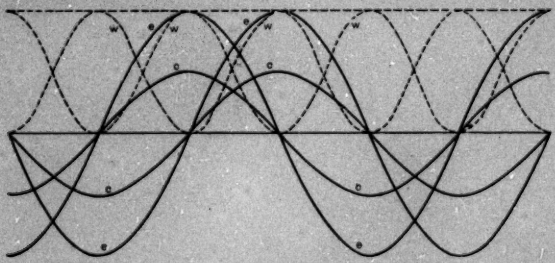


FIG. 4.

Thus the power of the alternating circuit is fluctuating and varies twice per period, that is with the double frequency of the E. M. F. or the current, between a maximum value and zero in the non-inductive circuit, between a maximum value and a negative maximum value in a circuit with phase displacement between current and E. M. F., in the latter case, passing twice through zero per half wave, as shown in the diagram Figs. 2 and 3, where the E. M. F. is represented by the drawn line e, the current by the drawn line c, and the power by the dotted line w.

In the polyphase system, as a quarter phase with two E. M. F.'s in quadrature producing two currents in quadrature, as in Figs. 4 and 5, or in a three phase system with three E. M. F.'s producing three currents, as in Figs. 6 and 7, the energy wave of each phase is fluctuating as in the single phase system. The sum of

all the energy waves, however, or the total flow of energy is constant.

From the law of conservation of energy, it follows thus, that a change from a single phase to a polyphase circuit or inversely, is possible only by means of apparatus able to store energy, and that the total amount of energy between the mean and maximum value in the single phase circuit must be stored and returned during the time the single phase wave is below the mean.

Means to store the energy are, electro-magnetism, electro-static charge, electro-chemical force and mechanical motion. Electro-magnetic and electro-static storage are in most cases excluded by low energy efficiency and especially low weight efficiency and inconvenience. Electro-chemical storage shows a very low efficiency, and the only efficient way of storing energy ap-

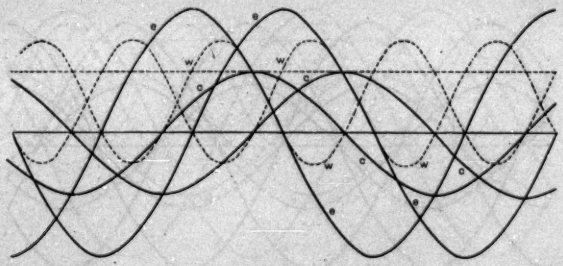


FIG. 5.

pears to be mechanical momentum. This offers a high weight efficiency also, but is for most cases excluded by the complication due to revolving machinery.

Excluding storage of energy, we see that the *nature of the flow of energy constitutes an essential feature of an alternating current system.*

The phase relation does not represent an essential feature, since, as seen, starting from a single phase generator we can get currents of different phase relation and E. M. F.'s of different phases, but if the currents are displaced in phase, the E. M. F.'s are in phase and inversely, so as to preserve the nature of the energy flow. Again, starting with a quarter phase generator we can transform by stationary transformers without storage of energy, that is at full efficiency, to

three phase and back again to quarter phase or five phase or any other symmetrical or unsymmetrical phase relation. In all these transformations, however, the nature of the energy flow remains constant. Hence the best classification of the alternating current system is by this feature, the classification by the number of phases having become meaningless with the possibility of transformation from one polyphase system to any other. Thus we shall call an alternating current system of constant flow of energy, a balanced system; an alternating current system in which the flow of energy pulsates between a maximum and a minimum, a system of balance factor x, where x is the ratio of the minimum value to the mean value or energy flow. Hence the balanced

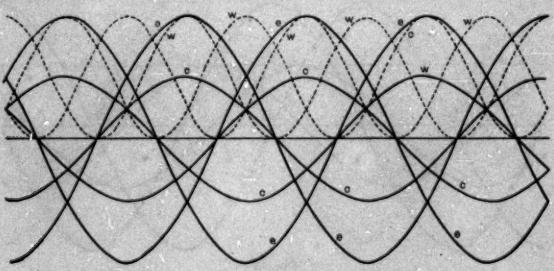


FIG. 6.

polyphase system has the balance factor, one; the single phase system the balance factor, zero.

I may add here that the names "polyphase" and "single phase" are really wrong, and the latter name meaningless, since "phase" becomes a meaning only as "difference of phase."

The systems are characterized correctly, not by the existence of one or several phases, but by the existence of one or several waves of energy, or cycles, and for this reason I rather prefer the denotation "polycyclic" for a system of many waves of energy, "monocyclic" for a system with one wave of energy. Hence:

The *monocyclic system* is an alternating current system of *balance factor zero.*

The *balanced polycyclic system* has the *balance factor one.*

The three phase or quarter phase system with equal load on all branches has the balance factor one.

A three phase system with two branches loaded and one unloaded has the balance factor .5.

A three phase system with one branch loaded and two unloaded has the balance factor zero.

A quarter phase system with one branch loaded and the other unloaded has the balance factor zero.

Still from another point of view, we are driven to recognize the importance of the flow of energy as characteristic in alternating current circuits.

In a continuous current circuit, the direction of transmission, or direction from the generator to the consumer circuit, is in the direction of decreasing voltage.

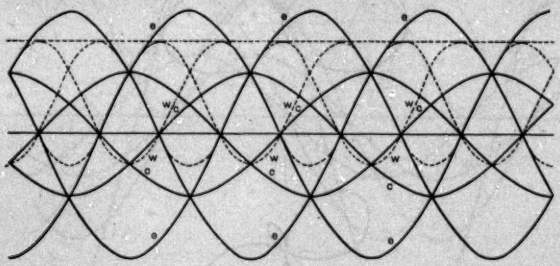


FIG. 7.

In an alternating current circuit, the voltage at the consumer terminals of the line may be higher than at the generator terminals of the line, and the power be transmitted from lower to higher voltage. This is the case in a line of noticeable inductance feeding into a circuit with leading current. Inversely the current received from the line at the consumer terminals may be larger than the current issuing from the generator into the line. This is the case with a line of noticeable capacity feeding into a circuit with lagging current. These features are made use of now in long-distance transmissions for controlling the potential and the current flow in line and receiver circuit.

Hence, the direction of transmission in an alternating current circuit is not necessarily the direction of decreasing voltage or de-

creasing current, but it is the direction of decreasing energy flow. That is, attaching a wattmeter to two points of the line, the wattmeter nearer the generator will always give a higher reading than that farther away from the generator.

An apparent disadvantage of this definition by the nature of the energy flow, is that with a change of the distribution of load, the nature of the system, or at least its balance factor varies. But in this case the characteristic feature of the system in reality changes. It is obvious, for instance, that if one branch of a three phase generator only is loaded, the circuit, as well as the gener-

FIG. 8.

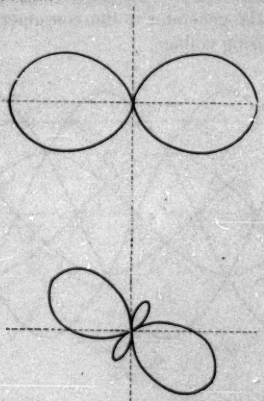


FIG. 9.

ator acts in every way as single phase and is indeed single phase, and the remaining generator circuit merely dead wire.

The total flow of power in an alternating current system can be represented also by a polar diagram, with the instantaneous values of power as radii vectors, and the angle corresponding to time as amplitude, one complete period being represented by a complete revolution or 360°. This gives a power diagram of the alternating current system corresponding to the compound indicator diagram of the steam engine.

In a single phase system of E. M. F.,

$$e = E \sin \varphi,$$

and current:

$$e = C \sin (\varphi - \tilde{\omega});$$

the power is:

$$w = e\,c = E\,C \sin \varphi \sin (\varphi - \tilde{\omega})$$
$$= {}^1/_2\, E\, C \{\cos \tilde{\omega} - \cos (2\,\varphi - \tilde{\omega})\},$$

and the average power:

$$W = {}^1/_2\, E\, C \cos \tilde{\omega}.$$

In polar coordinates, the power diagram of the two circuits shown in Figs. 2 and 3 is represented by Figs. 8 and 9; Fig. 8 representing a non-inductive circuit, Fig. 9 a circuit with 60° lag.

In a system comprising several E. M. F.'s and currents, in every

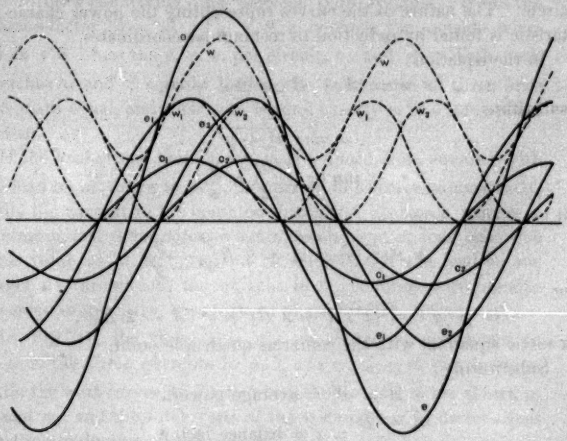


FIG. 10.

part of the circuit the power can be represented in the form:

$$w_1 = {}^1/_2\, E_1\, C_1 \{\cos \tilde{\omega}_1 - \cos (2\,\varphi - \tilde{\omega}_1)\},$$

and, adding the power values of all the circuits, we get for the total power of the system an expression of the form:

$$w = \Sigma\, w_1 = A + B \cos (2\,\varphi - \vartheta),$$

with the average value of power:

$$W = A,$$

the maximum value of power:

$$W_1 = A + B,$$

the minimum value of power:

$$W_2 = A - B.$$

The maximum and the minimum values of power take place at right angles with each other, or in quadrature, and we can thus speak of the two axes of the power diagram, the large axis W_1, and the small axis W_2.

The balance factor is:

$$K = \frac{A - B}{A}.$$

The balanced polycyclic system gives:

$$B = 0,$$

or a constant flow of power, which would be represented by a circle. The nature of the curves representing the power characteristic is found by reduction to rectangular coordinates.

In the equation:

$$w = A + B \cos (2\varphi - \vartheta),$$

substitute:

$$w = \sqrt{x^2 + y^2}$$

$$\tan (\varphi - \frac{\vartheta}{2}) = \frac{y}{x},$$

it is:

$$\sqrt{x^2 + y^2} = A + 2B \frac{x^2 - y^2}{x^2 + y^2}$$

or:

$$(x^2 + y^2)^3 = \{x^2 (A + 2B) + y^2 (A - 2B)\}^2,$$

a sextic equation, with the center as quadruple point.

Substituting:

$$A = W = \text{average power},$$

$$\frac{A - B}{A} = \varkappa = \text{balance factor},$$

gives:

$$(x^2 + y^2)^3 = W^2 \{x^2 (3 - 2\varkappa) + y^2 (2\varkappa - 1)\}^2.$$

In a single-phase circuit, it is:

$$\varkappa = 0,$$

$$(x^2 + y^2)^3 = W^2 (3x^2 - y^2)^2.$$

In a balanced polycyclic circuit:

$$\varkappa = 1,$$

$$x^2 + y^2 = W^2.$$

In a polycyclic system of balance factor:

$$\varkappa = .5,$$

$$(x^2 + y^2)^3 = 4x^4 W^2.$$

As an instance of a polycylic system of a balance factor less than unity, the "Inverted Three-phase System" ("polyphase monocyclic") may be discussed.

If in a three-phase system, two transformers are connected with their primaries into two branches of the system, and one of the secondaries is reversed with regard to the other, the two secondary E. M. F.'s $\overline{ac} = e_1$ and $\overline{cb} = e_2$ differ in phase by 60°, while the corresponding primary E. M. F.'s $\overline{AC}$ and $\overline{CB}$ differ by 120°.

The secondary system produced hereby has features in common with the three-phase as well as with the Edison three-wire system, and forms a connecting link between both systems. It has the balance factor: $x = .5$. The E. M. F. between the outside wires $a\ b$ is $\sqrt{3}$ times the E. M. F. per circuit, $\overline{ac}$ and $\overline{cb}$. With both branches $\overline{ac}$ and $\overline{cb}$ equally loaded, the currents in all three lines a, b, c are equal, and their sum is zero, exactly as in a three-phase system.

If the load of one branch, say $\overline{cb}$, is reduced from equality with the load on $\overline{ac}$, down to zero, the current in b decreases constantly, while the current in the common line c first decreases, reaches a minimum, and then increases again, reaching at no-load on $\overline{cb}$ the same value as at full load on $\overline{cb}$. That is, if the load on one branch is thrown off, the current in the common wire remains the same in intensity, but shifts in phase by 60°.

In Fig. 10, the three E. M. F.'s $\overline{ac}$, $\overline{cb}$ and $\overline{ab}$ are shown as e_1, e_2, e, the three currents in a, b, c as c_1, c_2, c, in drawn lines, while the watt-curves of the two branches $\overline{ac}$ and $\overline{cb}$ are shown as w_1 and w_2, and the total watts of the system as w, in dotted lines for a non-inductive circuit.

Fig. 12 gives the power diagram of the system in polar co-ordinates.

With an inductive circuit of an angle of lag of 60°, the balance factor of the system becomes $x = 0$, and the flow of power single-phase, as shown in Fig. 11 and 13.

In an alternating current system there is a certain tendency to maintain its balance factor.

Let us consider the field characteristic of an alternating current generator, that is, the interdependence of volts at the armature terminals and amperes at constant field excitation. Such a curve, the field characteristics of a 300 K. W. three-phaser used for long-distance transmission by step-up and step-down transformers,

is shown in Fig. 14 with the ampere output as abscissæ, and volts at armature terminals as ordinates, and the K. W. output as ordinates. The ampere-volt curve is similar to a quadrant of an ellipse, that is at and near open circuit, the voltage is approximately constant for variation of current, and the machine regulates for constant potential. At and near short-circuit the current is approximately constant for varying voltage, and the machine regulates for constant current. The output of the machine, as shown in dotted line in Fig. 14, increases from zero at open circuit, reaches a maximum of 345 KW, at 575 volts

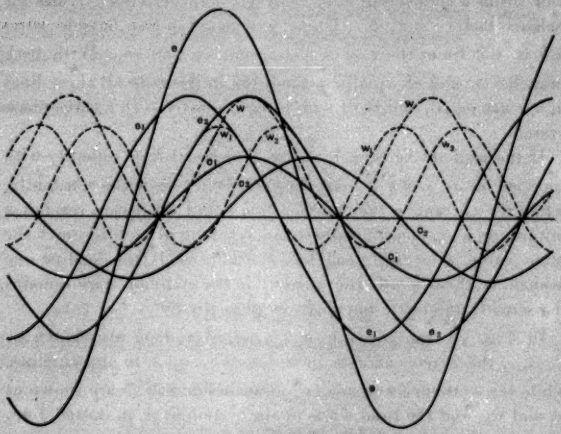


FIG. 11.

and 345 amperes, and decreases again to zero at short-circuit. Near the maximum output there is a wide range, where the machine regulates approximately for constant power. That is, an increase of current reduces the voltage, and a decrease of current increases the voltage, so as to maintain approximately constant power.

The proper working point of an alternator lies somewhat below, but quite near the maximum output point. Operating in this range near the maximum output point, but still far enough below to ensure sufficient synchronizing power for parallel running, the generator gives the best weight efficiency and energy

efficiency, and is most reliable in its operation in-so-far as it is very easy to synchronize without too careful and delicate adjustment, the cross-currents in parallel operation are insignificant and the machine will keep in step, even under very exacting conditions, as for instance, if the field circuit of one is broken, and will not be damaged or damage the prime mover by an accidental short-circuit of the system, or a falling out of step or any other such accident.

In a polycyclic machine in this range near the maximum output point, self-regulation for constant power takes place, not only for variation of the total load, but also for variations of the load between the different circuits. Thus, in a three phaser like the present one in Fig. 14, if the load of one circuit is decreased, the voltage in this circuit will increase, and the voltage in the two other circuits change so in size and phase as to restore the system, to a certain extent, to constancy of flow of energy, or in other words:

The multiple-circuit generator regulates, or tends to regulate, near the maximum output point for constancy of the balance factor. Thus, the polycyclic machine with balanced circuit regulates for constancy of the flow of energy; the monocyclic machine regulates for a balance factor zero.

This self-regulation takes place by a change of voltage and a shifting of phase of the different generator circuits. It is therefore in general objectionable.

A similar action takes place in multiple circuit motors, induction motors as well as synchronous motors, etc.

In the multiple circuit alternating current motor, as for instance, a three-phase induction motor, the counter E. M. F.'s in the different circuits are equal (or rather proportional to the respective number of turns of the different circuits).

If the impressed E. M. F.'s are equal, the currents flowing into the motor circuits are equal also, since they are produced by the differences between impressed and counter E. M. F.'s. If, however, the impressed E. M. F.'s become unequal, even to a small extent only, the differences between the impressed and counter E. M. F.'s become rapidly very different, and the currents thus unequal. For instance, if in the three-phase induction motor one of the E. M. F.'s falls by 10 per cent. below the other two, it will be equal with, or even less than the counter E. M. F., and the circuit of this E. M. F. will take no current, or will even return

current into the system, and the currents of the two other branches will increase correspondingly.

In this regard the multiple circuit motors are very sensitive, and a small variation in the size or the phase of the impressed E. M. F. causes a large variation in the currents, shifting the current from the branch of the low impressed E. M. F. to that of high

FIG. 12.

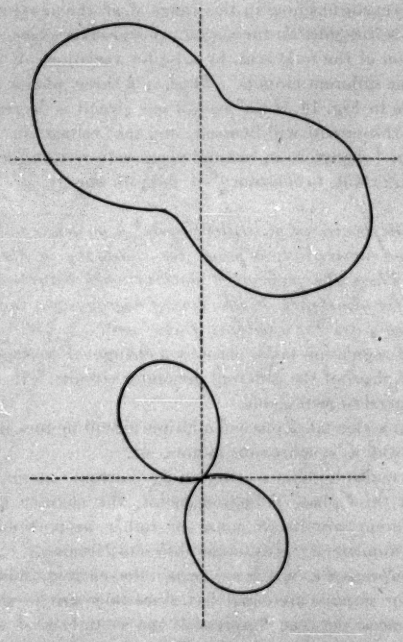


FIG. 13.

E. M. F. It is thus obvious that, with a considerable number of multiple circuit motors in the polycyclic system, even a large inequality in the distribution of the single phase consumer circuits, as lights, between the generator branches, will not unbalance the system. The generator will regulate for constant flow of

energy and tend to raise the voltage on the lesser loaded, to lower it on the more loaded branch. The motors, however, in this case take more current from the branch of higher voltage, the lesser loaded branch, and less current from the higher loaded branch, or even return currents therein and so restore the balance of the system with regard to constancy of flow of energy and constancy of voltage and of phase relation. This feature of automatic self-regulation for constancy of flow of energy by the generator, and constancy of voltage and phase relation by the motors, is with proper design of the system very marked, and holds the system balanced very closely, even within wide ranges of load.

As before stated, this self-regulation in reality tends towards constancy of the balance factor of the system. Thus in a monocyclic system, or a system with balance factor zero, as given by a standard monocyclic machine with main or energy coil, and teaser or supplementary coil, as soon as current is taken off from the teaser circuit the voltage therein drops, and thus reduces the current, and at the same time displaces it in phase so as to maintain the flow of energy pulsating, or with balance factor approximately zero.

It will be seen that all these features are internal reactions of the alternators and multiple circuit motors and the system in general, which, while probably noticed before, have not been understood and therefore considered as objectionable features, as for instance the "unbalancing" of the generator or the "unequal distribution of current" in induction motors. Recognized in their significance, these phenomena allow a very effective and perfect control of the alternating current system.

After this diversion we may return to the motor problem. As seen, the polyphase system, characterized by a constant flow of energy, promised a solution of the motor problem for polyphase circuits. But it was not possible to produce polyphase circuits from single phase alternators without storage of energy.

Thus it remains to be seen whether those features which made the induction motor work on polyphase circuits are essential features of the polyphase system or not.

The problem of the alternating current motor may be approached from still another side, from the viewpoint of adapting the continuous current motor to alternating current circuits. In similar lines to this, work has been done by Vandepoele, Eickemeyer, Stanley, myself, and others in this country, by Kennedy and others abroad.

The continuous current motor, as shown diagrammatically in Fig. 15, consists of two different elements movable with regard to each other, the field and armature. Rotation of the motor is due to the action of the magnetic field upon the currents flowing in the armature. Thus, the electric circuit of a continuous current motor consists of the field exciting circuit producing the magnetic flux which passes through and acts upon the armature, and the armature or power circuit whose current is sent through the armature by the brushes in such direction as to produce a current polarization at right angles (in a bipolar motor) to the magnetic field flux. The possibility of operating such a motor

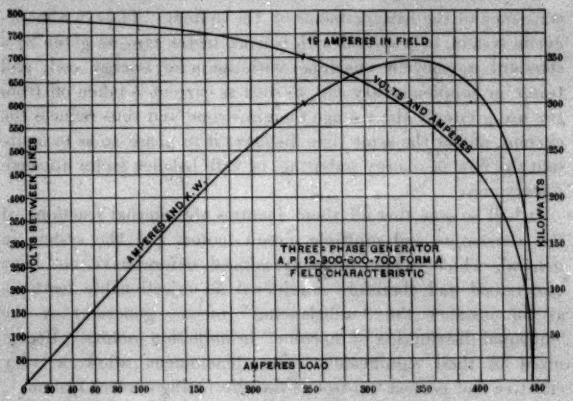


FIG. 14.

successfully is based on the feature that the armature coils when reaching the brushes are in a position where no E. M. F. is induced in them, and they can thus be short-circuited by the brushes, in their passage from the one to the other side, without sparking.

A simultaneous reversal of field magnetism and armature current does not change the direction of rotation of the motor. Thus, if an alternating current is sent through such a motor, proper care being taken to have the reversal in field and in armature take place simultaneously, the motor should be expected to operate also. Obviously thorough lamination of all the iron parts would be necessary to avoid eddy currents. Such motors, straight alter-

nating current series motors with laminated field, have been tried but have been a complete failure in all but the smallest sizes, as fan motors, due to their excessive and incurable sparking. As seen in Fig. 15, in the moment of commutation, the armature coil encloses the whole field flux, and thus in this moment does not cut lines of magnetic force by its rotation, that is, no E. M. F. is induced therein and commutation possible[1]. If, however, the magnetic flux is alternating, the armature coil under the brush which encloses the total alternating flux, is a short-circuited secondary to the field coil as primary, and thus, independent of its rotation by transformer action, an E. M. F. will be induced therein which tends to produce a current of the same M. M. F. as the field exciting coil. A numerical instance will show how excessive this current is. Assuming the total field exciting ampere-turns only as large as the armature ampere-turns, and only 10 commutator segments between brushes, then in the short-circuited coil, we will get nearly ten times as large a current as the main current, and thus in this one coil ten times the current-heating as in the whole other part of the armature. If the armature does not start instantly, this current will burn out the coil, but even if the armature starts, vicious and destructive sparking forbids the use of such a motor.

In the continuous current motor the use of brushes and thus of a commutator, constitutes the only way to produce the current in the armature. In the alternating current motor the required current in the armature can be produced by induction, by acting upon the armature as secondary in the proper direction by a primary coil, which may either directly surround the armature, as shown in Fig. 16, or surround additional pole-pieces as shown in Fig. 17. The apparatus in this case combines the features of the alternating current transformer with those of the direct current motor. It consists of an exciting circuit, producing the magnetic flux, and an energy circuit, stationary with regard to the exciting circuit. The energy circuit induces as primary in the armature as secondary, the current acted upon by the field magnetism. The armature current is in phase with, but in opposition to the primary current. The primary current will supply the power of the motor and is thus practically in phase with the primary main E. M. F. The field magnetism will be in phase with the armature current, that is in phase with the primary current.

1. In reality the brush position is shifted intentionally so as get some E. M. F. in the armature coil, which it required for forced commutation.

To get the field excitation in phase with the main current, the exciting current must be in phase with the main E. M. F. Since, however, in an alternating magnetic circuit, the magnetizing current lags approximately 90° behind the impressed E. M. F., it follows that the E. M. F. impressed upon the field circuit must be 90° ahead of the main E. M. F. Or in other words to produce in such a transformer motor a magnetic field in phase with the induced armature current, but displaced at right angles in space, a supplementary E. M. F. is required, approximately 90° displaced from the main or power E. M. F. Being in quadrature with its current, this E. M. F. represents no power, and thus need not be supplied by the generator, but may originate from a motor or other multiple circuit apparatus.

We see thus that the alternating current motor requires a sup-

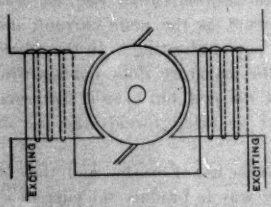


FIG. 15.

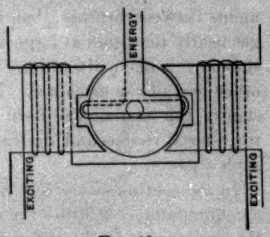


FIG. 16.

plementary circuit for its operation, the so-called "teaser circuit" of the monocyclic system. One difficulty, however, is met here. Since the movable armature acts as secondary to the stationary primary main circuit, the armature must contain a number of circuits closed upon themselves, but displaced in position from each other, so as to form in any position a secondary circuit to the primary.

In this case the armature circuit will form closed secondary circuits also to the field exciting circuits, and energy be supplied by the supplementary circuit, making this a power circuit. This would require the teaser circuit to have capacity enough to supply energy, and in short make a polyphase system. Thus, means have to be provided to avoid this feature. Since all the armature circuits pass through the same magnetic field, the E. M. F. induced therein per turn will be the same, and equal to that in the power circuit, less

the drop of voltage by resistance and reactance. If now the voltage of the exciting circuit per turn, is greater than that of the armature, transfer of energy will take place from the exciting circuit to the armature. If the E. M. F. is the same, no transfer will take place, and the exciting current will fulfil its purpose of mere magnetization. If the E. M. F. is less, energy will be transferred backward from the armature to the exciting circuit. Thus we see that to avoid energy transfer between armature and exciting circuit, the E. M. F. of the latter per turn, must be equal to that induced in the armature. At constant impressed E. M. F. on the primary power circuit, the E. M. F. induced in the armature decreases with increasing load; that is, increasing current. Thus at constant E. M. F. impressed upon the exciting circuit, at light load, the armature E. M. F. will be higher than the exciting E. M. F. and energy be transferred backward from armature to exciting circuit. At some intermediate load, armature and exciting circuit will be equal, and at higher load the armature E. M. F. will be lower than that of the exciting circuit, and energy be transferred from the exciting circuit to the armature. In this case, all exciting circuits being connected together, this supplementary circuit acts as an equalizing circuit in transferring energy from motors operating under light load, to motors operating under overload. While this action may be advantageous to a certain extent, it is obvious that the current flowing over the equalizing circuit should be as small as possible, because if a large energy current is allowed to pass over the teaser circuit, this circuit becomes an energy circuit also, and must thus have sufficient current capacity to carry the power. That means the generator becomes more or less a polyphase generator, and a distribution of circuits between the phases becomes necessary, the very feature it is intended to avoid. For this purpose the E. M. F. at the exciting circuit is not kept constant but reduced at increasing, increased at decreasing load so as to be always very nearly equal to the armature E. M. F., and this is done by giving the teaser or supplementary circuit a sufficently large resistance and reactance, so that an increase of current drops, and decrease raises the E. M. F.

We have now arrived at the modification assumed by the continuous current motor in its adaption to alternating current circuits:

1st.—The armature current is induced by a primary energy circuit, instead of being led in by brushes.

2nd.—To keep the field excitation in phase with the armature current, it is derived from an auxiliary circuit of displaced E. M. F.

3rd.—To avoid energy transfer between field exciting circuit and armature, the E. M. F. at the terminals of the field exciting coil is kept approximately equal to the E. M. F. induced in the armature, by the internal reactions of the system.

This is the monocyclic motor.

The calculation of such a motor is now simple, and done on the hand of the previous explanation of its action. The torque, and thus the output of the motor, are determined by the field magnetization, the armature current, and the angular space displacement between them. The field magnetization is determined by the impressed E. M. F. of the exciting circuit, and the arma-

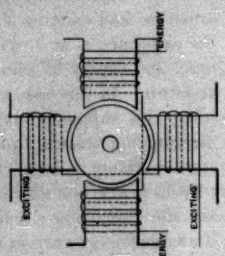


FIG. 17.

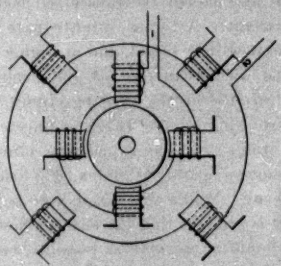


FIG. 18.

ture current is determined by the equations of the alternating current transformer, as secondary currents induced by the primary energy current. Since no energy transfer should take place between the exciting circuit and the armature, it follows that the counter E. M. F. at the exciting circuit, is equal to the E. M. F. induced in the armature, and thus the magnetic flux can be calculated from the latter.

This leads us to the theory of the induction motor as outlined by me in the TRANSACTIONS of 1894 p. 669, equations as seen strictly analogous to those of the alternating current transformer.

Since the E. M. F. required at the terminals of the exciting circuit, in such a motor, is in quadrature with the main E. M. F., obviously such a motor could be operated from a quarter-phase

circuit also. It would in this case, however, offer the disadvantage of loading the two circuits unevenly, the one circuit with a large energy current in phase with the E. M. F., the other circuit with a small and lagging exciting current.

An equal load on both branches of the system can be secured by using a double motor. In this case the first phase is used to feed the energy circuit of the one, and the exciting circuit of the other motor, the second phase for feeding the exciting circuit of the first, and the energy circuit of the second motor. Going still a step further, one and the same field pole can be used for exciting the field of the one, and inducing the armature currents of the other motor, by cross-connecting the armature, or using one armature within two fields placed side by side of each other, as outlined diagrammatically in Fig. 18. As you see, we get here our well-known friend the Stanley motor, consisting of two armatures with common winding acted upon by two fields, in such a way that each field sends the magnetic flux through the armature, and at the same time induces currents in the armature winding which are acted upon by the magnetic flux produced by the other field.

Going still a step farther in this direction, one armature only may be used in one double field, by bringing both sets of field poles into the same plane as shown diagrammatically in Fig. 19. Here we have two magnetic field fluxes in quadrature with each other, each acting upon the currents induced in the armature by the other flux. Obviously it is unessential theoretically whether we have a double motor with two fluxes in quadrature, or a triple motor with three fluxes under equal angles. The equations of the motor and its calculation remain the same as mentioned above.

As seen, starting from the continuous current motor, by successive steps we arrived at the so-called "rotary field motor" without making use of the hypothesis of the revolving field. In the last type of motor and to a lesser extent in the preceding types, the action of the motor can also be explained thus:

The E. M. F.'s of displaced phase impressed upon the motor circuits, produce currents in these circuits which combine in their magnetizing action to a resultant M. M. F. This resultant M. M. F. rotates at constant, or approximately constant, intensity, and at a uniform velocity, the velocity of synchronism, through the motor field, and produces thereby a system of rotating magnet

poles, which by their drag upon the currents induced by them in the armature, cause the armature to revolve. This theory is very beautiful by its simplicity. It has, however, the disadvantage of not giving due prominence to the transformer feature of the motor and to the multiple circuit feature. Therefore, it has not proved suitable as far as I know for the calculation of such motors, and has in this regard rather retarded the progress of induction motor design, by deflecting the attention from the multiple circuit transformer feature of the motor. If, for instance, in the motor in Fig. 19, one of the circuits was opened, the field should be expected to change from rotating to pulsating, that is varying between maximum and zero. It does not change, however, but remains the same. But under certain circumstances, the rotation of currents may even be in opposition to the rota-

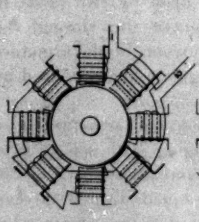


FIG. 19.

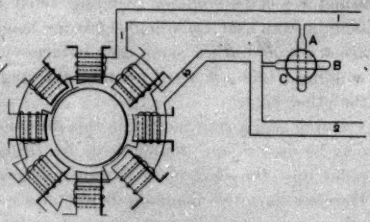


FIG. 20.

tion of the motor amature. Inserting in the two circuits of the motor in Fig. 19 a field exploring device consisting of two small coils A and B, Fig. 20, in quadrature with each other, and with a light movable iron disk C in their common center, we can by the rotation of this iron disk find the so-called rotation of the currents in the two circuits, and its direction. If equal E. M. F.'s are impressed upon the two circuits of the motor, the iron disk C will rotate rapidly in the same direction as the motor armature. Reducing one of the two E. M. F.'s gradually, we should expect to see the rotating field change from uniform rotation to elliptical rotation, so that, for instance, if B is 10 per cent. lower than A, the "rotating field" should pulsate by 10 per cent. In reality the action of the motor is such as would require a constant and uniformly rotating field for its explanation.

The strangest feature, however, is the behavior of the iron disk C. With increasing difference between the E. M. F.'s, A and B, the disk slows down, comes to rest, and then begins to revolve in the opposite direction, showing that one of the currents has reversed, and the direction of rotation of the primary currents in the motor and thus their M. M. F's. is reversed. The motor, however, keeps on revolving in the same direction as before, that is in opposite direction to the primary currents. The explanation of this phenomenon follows from the preceding discussion of the multiple circuit transformer feature of the motor. With the decrease of the E. M. F., B, the transformer action between armature and circuit B reverses its sign, and current returns from B. Thus, with increasing difference between A and B, the current A constantly increases while B decreases, reaches a minimum when the exploring disk C stops, and then increases again. This experiment is very instructive in showing the internal reactions of the induction motor.

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y., June 26th, 1895. President Duncan in the Chair.

SOME OBSERVATIONS ON A DIRECT-CONNECTED 300 K. W. MONOCYCLIC ALTERNATOR.

BY DUGALD C. JACKSON AND S. B. FORTENBAUGH.

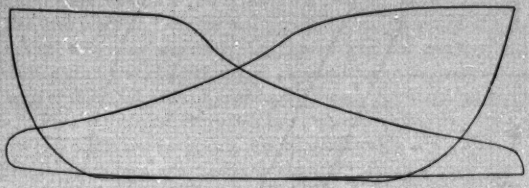
Before giving the results of the observations we have taken, it will probably be desirable to give a brief description of the machine.

The machine is the new monocyclic alternator, manufactured by the General Electric Company, of 300 K.W. capacity—1150 volts, 260 amperes—at a speed of 140 revolutions per minute. It is direct connected to a Russell, tandem-compound, high-speed condensing engine, which ran during the test about 15 revolutions more than the required speed. The armature is of the ironclad type, 110 inches in diameter, $10\frac{1}{2}$ inches wide, with about $\frac{3}{16}$ inch clearance, and is furnished with two sets of windings.

According to Dr. Louis Bell the cross-section of the main and teaser coils is the same, but the latter has fewer turns and is placed in shallower slots midway between the main coils. The pressure developed by the teaser coils was .7 of the pressure across the main terminals of the machine. There are 96 slots on the armature, one-half of these being used for the main coils and the other half for the teaser coils. Three collector rings are used, one being connected to each end of the main coil, and one to the free end of the teaser coil. These are made of brass, 2 inches wide and $\frac{1}{4}$ inch thick, and each has two brushes, $\frac{5}{16}$ inch thick, covering its full width. The rectifier for the series excitation is $4\frac{1}{2}$ inches wide and has 48 segments $1\frac{1}{4}$ inches in width. Two sets of brushes are used for both the positive and negative poles of the rectifier, each set consisting of two copper brushes $1\frac{3}{4}$ inches wide by $\frac{5}{16}$ inch thick. Only about .63 of the total cur-

rent is rectified in this machine. The magnet cores are laminated, 48 in number, and are 10 by 4¼ inches face and 10¼ inches deep, the outside dimensions of the field windings being about 12 by 6 inches. Each magnet spool carries a series coil, and a separately excited coil, all the series and separately excited coils being separately connected in series.

The series coils are formed of two flexible cables in parallel, having a total cross-section of about 98,000 cir. mils. while the cross-section of the separately excited coils is about 33,100 cir. mils.



Indicator Card from High Pressure Cylinder. 60 lb Spring. Speed 146. Total I H. P., High Pressure 126.3 E. H. P. 190.

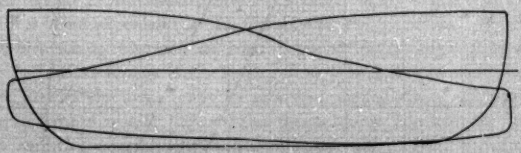


FIG. 1. Indicator Card from Low Pressure Cylinder, 20 lb. Spring. Speed 146. Total I. H. P. Low Pressure Cylinder 107.8 E. H. P. 190.

The exciter used was a four-pole continuous current machine, of the new General Electric, slow-speed type, belted direct from the dynamo shaft, and therefore all power measurements include the power furnished to the exciter. The output of the exciter is 52 amperes at 125 volts, and its speed 850 revolutions per minute. Standardized Weston instruments were used, with the exception of the main ammeter in the generator circuit, this being the regular station instrument furnished by the General Electric Company. This instrument was quite sensitive, and, while no means were at hand for calibration, we think the results

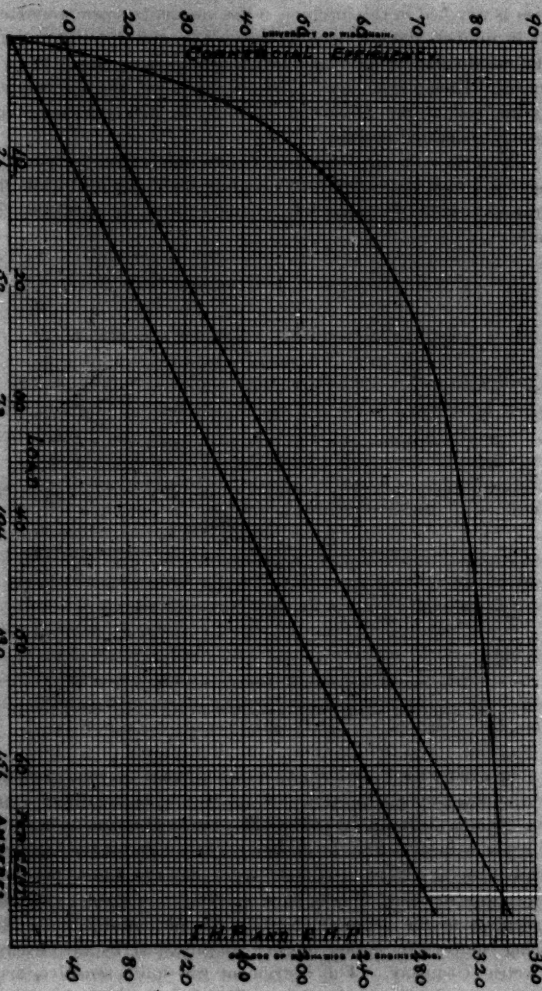

10
20
30
40
50
60
70
80
90
24
52
79
104
130
156
AMPERES
40
80
120
160
200
240
280
320
360

Fig. 2.

may safely be taken as a fair indication of the performance of the machine. The principal dimensions of the engine are as follows: Stroke 24 inches, diameter of high pressure cylinder 15 inches, diameter of low pressure cylinder 24 inches.

Figure 1 represents a set of cards taken from the engine and following are the electrical readings taken at the same time—124 amperes, 1144 volts, 146 revolutions per minute. The exciting current was 51 amperes.

In planning the test we fully expected to make a ten-hour continuous run at full load, and determine the heating, efficiencies, etc., but were unable to go farther than slightly above half load. In the first place the engine was piped to a single boiler of insufficient capacity, and secondly, the engine was too small to carry the full load of the generator, and in addition its regulation was defective, the total variation of speed being as much as 15 per cent. Figure 2 therefore shows an efficiency curve for slightly above half load, and from this it will be seen that the commercial efficiency of the generating set is about 81 per cent. at half load. When these observations were made, the machine was in commercial service with the regular transformer load. The commercial efficiency of the generating set is taken as the ratio of the electrical output to the I.H.P. The E.H.P. here used is taken as the product of amperes and volts, the power factor of the circuits therefore being assumed at 100. Actual measurements have shown that the power factor is at any rate over 98 per cent., and consequently the error made by this assumption is comparatively small. The diagonal lines in the figure show respectively the I.H P. and the E.H.P. at different loads, the vertical scale for these being at the right hand of the figure. For the ordinary changes of load, the regulation of the alternator is not entirely effected by the series coils as the machine now stands, but requires considerable hand regulation. However, this can probably be improved by altering the shunts across the rectifier and series turns respectively, thus giving a greater number of ampere-turns in the series coils. This lack of regulation on the part of the alternator combined with the unsatisfactory regulation of the engine, makes the performance of the generating set somewhat below the standard for this class of machinery when under ordinary working conditions, but, as a whole, the unit is a magnificent piece of mechanical construction.

Discussion.

Mr. E. J. Berg :—This paper states that the cross-section of the teaser coil was about the same as that of the main coil. It ought to read one-quarter. The cross-section of the conductors in the teaser coil is the same as the cross-section of the conductors of the main coil, but the number of turns of the teaser winding is only one-quarter of that of the main winding, and thus the total cross-section is but one-quarter that of the main coil. In consequence thereof, the E. M. F. of the teaser coil, which is stated in the paper to be .7 of that of the main coil, is only .25. The E. M. F. observed by the writer of the paper is probably the difference of voltage between main and teaser collector ring, and thus is at open circuit .57 of the potential between the mains.

Mr. Gano S. Dunn :—I would like to inquire the reason for such a high power factor with the conditions under which the machine was running?

Prof. Fortenbaugh :—The power factor was determined by using a large wattmeter, after being carefully calibrated, and simply taking the ordinary meter readings, amperes and volts.

The ratio of the product of the amperes and volts to the wattmeter readings gave us the power factor of about 98¼ per cent. The machine was in ordinary commercial lighting service, and these readings were taken on only one of the regular lighting circuits, and assumed to be practically the same on all of them.

I am much obliged to the gentleman who made the corrections. In regard to the cross-section of the main and teaser coils, I will simply say that my information was taken from an article by Dr. Louis Bell, which, I think, was recently read before The National Electric Light Association.

As regards the ratio of the pressures between the mains and teaser wire, I have here one reading in which the E. M. F. between the terminals is 1,100 volts, and that between the teaser and either one of the terminals is 760. This gives a ratio of about .7 approximately, with no current on the teaser wire. It may not be absolutely correct, but that is a fair average reading on this particular machine.

The generator load corresponding to these readings was 160 amperes, and the current in the series field was 104 amperes.

Mr. Steinmetz :—I think I can explain a part of this discrepancy regarding the voltage between the main and teaser collector ring. As I showed in my last paper, there is a tendency in the alternating current generator to regulate for constancy of balance factor. This means that in this particular case, if the generator main coil is loaded, the main voltage will drop more than the teaser voltage, or in other words, since the machine is compounded, the teaser voltage will rise, and thus give a somewhat greater difference of potential between main and teaser coil. Inversely, if the teaser coil is loaded, as by induction motors, its

voltage will drop, and so the ratio between teaser voltage and main voltage be reduced. This is plainly shown in the variations of terminal voltages on an induction motor operated from the monocyclic system. I have here (Fig. 1) the characteristic curves of a standard 15 H. P. induction motor operated from a monocyclic generator by means of two transformers connected with their primaries between teaser and main line, while one of the

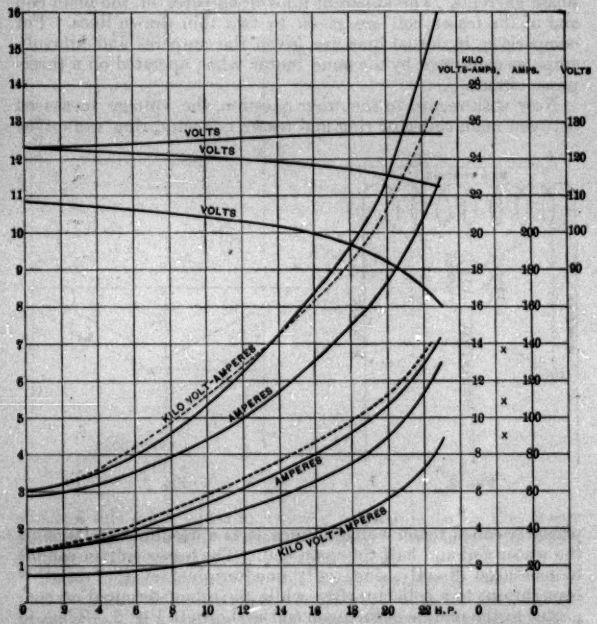


FIG. 1.—15 H. P. Induction Motor on Monocyclic and on Three-phase Circuits.

secondaries is reversed with regard to the other, thereby changing the relative displacement of the E. M. F.'s from approximately 60° in the primary to approximately 120° in the secondary, and giving approximately an equilateral triangle. At no load, the three secondary E. M. F.'s are, as seen from the diagram, 124, 124 and 109 volts, the lowest E. M. F. being that corresponding to the teaser voltage. With increasing load on the motor, and increasing current taken by it, the teaser voltage drops rapidly and

reaches 80 volts at 22½ H. P., while the two other voltages, which are composite voltages, or resultants of main and teaser voltage, have changed to 127 and 113 volts. The difference between them is due to the interaction of main and teaser circuit caused by the tendency of the generator to maintain its balance factor. Incidentally I may remark that on the same curve sheet are shown in drawn lines the amperes consumed by the motor, the large value representing the common return of the two essentially single-phase currents. The apparent kilovolt-amperes of the main coil and of the teaser coil are given by two thin drawn lines. For comparison, in dotted lines are given the amperes and kilovolt-amperes consumed by the same motor when operated on a three-phase circuit.

Now with regard to the other question, the voltage measured between main collector ring and teaser collector ring cannot be

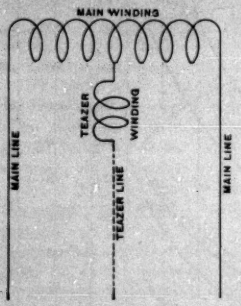


FIG. 2.

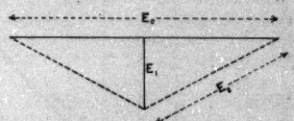


FIG. 3.

properly called teaser voltage, since it is a resultant voltage of the teaser coil and half the main coil. The teaser voltage cannot be measured directly, since only one terminal of the teaser is brought out to a collector ring, while the other terminal is connected to the middle of the main coil as shown in Fig. 2. Thus, to determine the teaser voltage we can either proceed by calculation by measuring the voltage between teaser collector ring and main collector ring, $= E_2$ and the voltage between the main collector rings $= E_0$. The teaser voltage is then

$$E_1 = \sqrt{E_2 - \left(\frac{E_0}{2}\right)^2}$$

as seen in the E. M. F. diagram Fig. 3. Another way to determine the teaser voltage by measurement, is to separate it from the main voltage by transformation, by connecting two trans-

formers between teaser and main lines and reversing the secondary of one transformer as shown in Fig. 4. We thus get the primary E. M. F., diagram Fig. 5, where A B is the main voltage, C D the teaser voltage, and A C and B C the two voltages between teaser and main coil, that is the voltages at the transformers. The reversal of the one transformer, reverses one of these E. M. F.'s B C, and thus gives the secondary E. M. F. diagram *a b c*, and in this diagram which is approximately an equilateral triangle, the

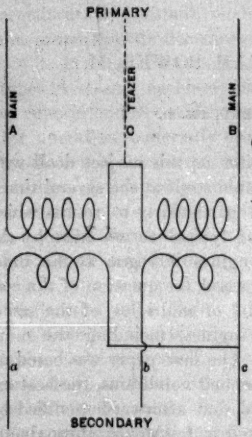


FIG. 4.

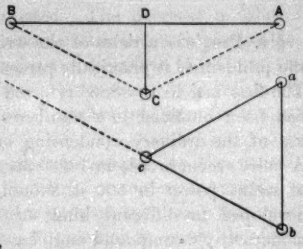


FIG. 5.

smallest side *a b* is equal to twice C D, that is twice the teaser voltage, times the ratio of transformation. In this way the teaser voltage can be separated by transformation.

PROF. FORTENBAUGH:—In this paper we should have stated that the ratio of the pressures was about .7 with no load on the teaser wire. We had no way of measuring this pressure when the teaser wire was loaded, simply because it was not in use.

(Recess till 8 P. M.)

A paper presented at the Twelfth General Meeting of the American Institute of Electrical Engineers, Niagara Falls, N. Y. June 20th, 1895 President Duncan in the Chair.

THE COST OF STEAM POWER. II.

BY CHAS. E. EMERY, PH. D.

§ 1. Previous articles of the writer on this subject dealt with the problem as it practically presented itself at the several times. The first article in 1883[1] referred particularly to results which had been obtained in a number of typical cotton mills by the use of the ordinary condensing engines in vogue at the time. A more recent article in 1893[2] discussed the question of the cost of steam power in 500 H. P. units or multiples of the same, developed in different kinds of engines, including the more modern triple compound engines. The first paper was based on actual conditions, the second on assumed conditions, the best experimental results being considered, but afterward modified by judgment so as to give a final result which would approximate the conditions of ordinary average working. In a later and more general article published in 1895[3] the method employed to increase experimental results to an approximately practical basis was outlined, but otherwise the inquiry was extended little or no further than before.

§ 2. In connection with the proposed supply of power in large units from Niagara Falls and other undertakings of a similar character, the question naturally arises: What would be the cost of steam power if also supplied in large units and generated with modern machinery of the most approved type? The question would be a simple one if it involved only the amount of coal consumed at a definite price, and the labor required to handle

1. Trans. Am. Soc. C. E., vol. xii., p. 425, Nov. 1883.
2. TRANS. Am. Inst. El. Engrs , vol. x., p. 119, March, 1893.
3. *The Engineering Magazine*, vol. viii, p. 796, Feb. 1895.

the coal and attend to the machinery. It is very common to compare the value of two engines simply by the relative amount of coal consumed, assuming that other costs incident to the development of the same power will be the same in all cases. Even if the assumption be substantially correct it has a more important bearing on the result than appears at first sight. The cost of coal is for ordinary engines of moderate size only about one-third of the total cost of steam power, so, if the other costs remain nearly constant, moderate savings in the cost of coal will not proportionally decrease the cost of the power.

§ 3. In large plants operated nearly at full capacity, the best types of steam machinery can be profitably employed, the cost of superintendence will be reduced and the cost of labor required for operation materially decreased. The decrease in labor depends largely on the size of steam unit it is found practicable to employ. Triple compound engines of 10,000 to 15,000 H. P. each, are used quite successfully in our large ocean steamers, but it is considered that these units are altogether too large for the problem we are considering.

§ 4. Any supply of power must be adapted to the nature of the demand, which for most industrial operations is variable, and it is desirable to make the steam units of such size that one or more of the same can be grouped together to carry the load at any time, without either overloading or greatly underloading either of such units. In a large plant, upon which presumably many different manufactories depend for power, there should be a spare unit which can be used in case of accident, and ordinarily employed in regular turn, so that all the machinery can be kept in repair.

§ 5. It will thus be seen that the size of the units is limited by the conditions above stated. If 20,000 H. P. as a maximum were to be delivered, two units of 10,000 H. P. each would do the work, but evidently the spare engine would require also to be 10,000 H. P. and this would involve too large an amount of capital in spare machinery. At Niagara Falls four connected turbines and dynamos of 5,000 H. P. each are being erected in a preliminary plant, so that only 15,000 H. P. maximum can be delivered if the principles above outlined are strictly carried out, though evidently contracts can be drawn to provide that the power may be stopped in case of accident, the same as in a private establishment, and thereby all the wheels and engines put

in service at the same time, but it is probable that one unit will be practically kept in reserve and more units added as the demand warrants. With steam power there would be some advantages for a 20,000 H. P. plant in adopting a unit of 2,500 H. P., on which basis with one spare unit of this size there would be nine such units in all. There is an advantage in having all the engines alike, as the parts required for repairs are then duplicates of each other, the units can be more suitably arranged in the building, and the labor better distributed. When it could be done without too much detail, it would be desirable to couple together several engines of 2,500 H. P. each, so that they would be capable also of independent operation. Another method would be to disregard absolute uniformity when so much power is to be delivered, and have several duplicates of two different units, say one of 2,500 H. P. and another of 5,000 H. P., which would either require the size of the spare engine to be increased, or that the other engines be slightly overworked in case of accident. For simplicity, however, all the costs will be assumed alike with either arrangement.

§ 6. The average cost per H. P. when the load is variable is considerably greater than if the power be furnished continuously. Coal is wasted in building up the fires and in caring for them when not required, all supplies are increased from the necessity of starting new after every stoppage, and there is an important loss due to the interruption of the regular hours of labor. A sufficient force must be kept on hand at all times to provide for any demand, and the watches of the men arranged in some practical way so as to proportion the labor to the work to be done as nearly as possible.

§ 7. It is desirable at the outset, however, to ascertain what steam power will cost under the most advantageous conditions as to demand, and we therefore submit a preliminary estimate based on the assumption that 20,000 H. P. can be sold for every hour in the year. The details of the estimate are discussed afterward.

§ 8.

TABLE I.

SHOWING COST OF STEAM POWER ON BASIS OF GENERATING 20,000 H. P. CONTINUOUSLY EVERY HOUR IN THE YEAR.

			Per Cent. of Total Cost.
	Yearly cost of coal for 20,000 net H. P. operated continuously every hour in the year, based on a consumption of 1.25 pounds of coal per indicated H. P. per hour, § 10. Cost of coal assumed at one mill per pound, or $2.24 per ton,		
1.	§ 12. Engine efficiency assumed at 92.3 per cent, § 11..	$287,250	43.4
2.	Estimated cost of labor, § 13	60,444	11.1
3.	Estimated cost of supplies and regular repairs, § 14.....	105,120	19.2
4.	Estimated interest, insurance, taxes and cost of renewals, § 15—16	144,000	26.3
5.	Total..... ...	$546,814	100.0
	Which divided by 20,000 gives the following :		
6.	Cost of steam power per H. P. per year, on basis of 20,000 H. P. delivered every hour in the year.....	$27.34	
7.	Cost of steam power per H. P. per year on above basis, if 5 per cent. of the original cost of plant, § 16, be charged for dividends, and $1.00 per H. P. added for general business expenses, § 18 ..... 27.34 + 3.60 + 1.00 =	31.94	
8.	Cost of steam power per H. P. per year on above basis, if 10 per cent. of the original cost of plant, § 16, be charged for dividends, and $1.00 per H. P. added for general business expenses, § 19 ..... 27.34 + 7.20 + 1.00 =	35.54	

§ 9. This cost is, for reasons which will be discussed later, lower than it is probable any plant can be operated under commercial conditions. This price is somewhat higher than those given in the papers previously mentioned, simply because operation is supposed to be continued every hour in the year.

§ 10. The cost of coal above outlined is derived as follows: The best triple compound engines have developed a H. P. for a little less than 12 pounds of water per H. P. per hour, and boilers have been constructed which at actual pressure from actual temperature of feed, evaporated 10 pounds of water per pound of first quality coal. Both these results are under experimental conditions, but we must assume that in a large plant like this, all details will be so well attended to that fair experimental results may be obtained all the time. We therefore assume that the power will be produced regularly for $1\frac{1}{4}$ pounds of coal per indicated horse-power per hour which would be obtained with engines requiring $12\frac{1}{2}$ pounds of feed-water per H-P. if the boilers evaporated 10 pounds of water per pound of coal, or if the boilers evapora-

ted 9.6 pounds of water per pound of coal and the engines only required 12 pounds of water per H. P. per hour.

§ 11. For permanent work of the kind assumed, engines of comparatively slow speed should be selected and, although some of the work might be directly connected, part of it at least would necessarily be operated by some method of transmission. The frictional losses of the engines and the more important features of transmission to the work done have been assumed at 7.69 per cent., so that the amount of coal per indicated horse-power above assumed must be increased by $\frac{1}{13}$ to give the coal per net H. P.

§ 12. The cost of coal per ton varies greatly in different parts of the country. The actual cost of mining bituminous coal is as low as 25 cents per ton in some locations, and the coal can be delivered on the cars at a good profit at 50 cents per ton. At deep mines the cost of mining is greater, but in all cases the principal cost of coal is the transportation, which has been reduced from time to time by increasing the size of the coal cars and the weight of the train, and by reducing the grade in the direction of traffic, until it is credibly stated that coal can be hauled on the main trunk lines, at a profit, for one-half cent per ton per mile, thus adding only $0.50 per ton for each 100 miles of haul. The lateral roads with undulating grades cannot haul coal at as low a rate as this. There is, moreover, to be added the general selling expenses, so it has been assumed that along the lakes, although comparatively near coal mines, the best quality of coal will cost but little over $2. per ton if purchased in large quantities, though this price must be increased on the seaboard fully 75 cents, and for ordinary consumers, of course much more. The price upon which comparison has been made is one mill per pound or $2.24 per ton, to include the cost of delivery directly in front of the boilers. The cost in line 1, § 8, is derived simply by multiplying the net power, 20,000, by $1\frac{1}{4}$, the coal per indicated horse-power, adding $\frac{1}{13}$ to allow for friction, and multiplying the result by 8760, the number of hours in the year, and $0.001, the price per pound. It appears that some kinds of coal can now be bought in Buffalo for $1.50 per ton. Adding only 25 cents per ton for the delivery of such coal directly in front of the boilers, and the taking away of the ashes, both of which are included in the price $2.24 given above, the cheaper coal need only have an evaporation of $10\ (1.75 \div 2.24) = 7.81$ pounds of water per pound of coal to make the total cost of the coal the same as for the higher priced

coal with an assumed evaporation of 10 pounds stated in § 10. It is much more probable that 7.81 pounds evaporation will be obtained from commercial coal, than that 10 pounds will be obtained, on the average, from a higher priced coal, so the cost of coal stated in line 1 of the several tables is a fair one for existing commercial conditions. The next item, that of labor, is made up as follows:

§ 13. Without attempting to arrange watches, it is assumed that on the average there would be required in such a station at all times

One attendant for each 2,500 H. P. engine, or 8 men in all, at 25 cents per hour	$2.00
14 firemen and 3 additional men at the same pay to care for pumps, etc., and to keep the premises clean; total, 17 men at 20 cents per hour	$3.40
Total cost of labor per hour	$5.40

There would also be required a chief engineer, 3 assistant engineers and some clerical help, which under the head of superintendence would cost, say, $13,140 per year, or $1.50 per hour, making a total of $6.90 per hour. The total cost for labor and superintendence for one year of 365 days, or 8760 hours, at $6.90, is $60,444 as given in line 2 of § 8.

§ 14. The cost of supplies and repairs in connection with the boilers and large condensing engines in the cotton mills of Fall River, proved upon investigation several years ago to be approximately $\frac{8}{10}$ of a mill per H. P. per hour. With the hope that this cost can be reduced in an immense plant of this kind the quantity in line 3 has been extended on the basis that the cost will be only 0.6 mill.

20,000 H. P. × 8760 hours × $0.0006 = $105,120, as written in line 3 of § 8.

§ 15. The above estimates only provide for regular repairs. Independent of this, a certain percentage oft he first cost should be put at interest every year to provide for renewals of the machinery, and provision made also for paying taxes and insurance. Calling these three, 5 per cent. of the cost, and considering that a company which can build so large a plant can possibly borrow money at 5 per cent., 10 per cent. of the total cost will be required for these several items.

§ 16. The total cost of such a plant cannot be determined accurately in advance. The present prices for steam machinery

are very low, and it might be possible to buy engines of the best type with necessary boilers, ready for erection for $30 per H. P. To this price, however, must be added the cost of the land upon which the plant is to be erected, the cost of foundations, of erection, of the buildings, of the chimney, the pipe connections, the general means of transmission, and the multitude of minor details required for fitting up such a place ready for use. The probable cost has been fixed at $64. per H. P. and as at least ¼ surplus power will be put in the station, there will be required a steam plant of 22,500 H. P. which at $64. will cost complete $1,440,000, 10 per cent. of which as required above is written in line 4, § 8.

§ 17. Referring to line 6, § 8, we find that the "Cost of steam power per H. P. per year on the basis of 20,000 H. P. delivered every hour in the year" is $27.34. The price at which this power can be sold to consumers, will depend upon the way the company furnishing the power is organized. The interest on the cost is already provided for in line 4, so the net cost given, viz: $27.34, would be that chargeable to power if the same company that built the works used the power, or if an association of individuals should build the plant and simply charge themselves with its cost.

§ 18. If, however, a private company with ample means should build the plant on a cash basis and wished to sell power and realize a return of 5 per cent. on first cost, independent of interest on the money invested, the modified cost would be $27.34 plus 5 per cent. of (64 × 1½ =) $72. (§ 16) viz $3.60, to which should be added, say, $1 per H. P. for general business expenses, making the total charge $31.94 shown in line 7, § 8, the same method being used in reference to similar lines in Tables II. and III.

§ 19. If, however, the promoters desired 10 per cent. profit on original cost, or a proportionally less percentage on stocks and bonds issued in excess of first cost, the modified cost per H. P. per year would be $27.34 plus 10 per cent. of $72. (§ 18) viz $7.20, to which adding $1 per H. P. as before, for general expenses gives as the total charge under these conditions $35.54, shown in line 8, § 8, the method applying to Tables II. and III. as above explained.

§ 20. We are now prepared to ascertain the variations in result which would be produced if the power were considered variable. For this purpose let us assume there will be sold:

	H. P. Hours.
1. 20,000 H. P., 10 hours per day	200,000
2. 12,000 H. P., 10 hours per day	120,000
3. 5,000 H. P., 4 hours per day	20,000
4. Total daily H. P. hours	340,000

which would probably be required on, say, 309 working days in the year.

5. Total H. P. hours, 309 days	105,060,000
Then if 5,000 H. P. were required for the remaining 56 holidays in the year :	
6. Total H. P. hours, 56 days of 24 hours, 5,000 H. P	6,720,000
7. Total H. P. hours per year	111,780,000
Average H. P. per hour during the year :	
8. Previous result ÷ 8760 =	12,760 H. P.

The average H. P. is therefore 63.80 per cent. of the maximum. This percentage is frequently termed the "power factor," and is rather higher than has been found in practical cases heretofore. An estimate of the cost on this basis will be given in advance as before, and explained afterward.

§21.

TABLE II.

SHOWING THE COST OF STEAM POWER ON BASIS OF GENERATING 20,000 H.P. MAXIMUM, AND AN AVERAGE OF 12,760 H. P. FOR EVERY DAY IN THE YEAR.

		Per cent. of total cost.
1. Yearly cost of coal, § 29	$157,644	37.3
2. Estimated cost of labor, § 23	47,652	11.3
3. Estimated cost of supplies and regular repairs, § 25	73,584	17.4
4. Estimated interest, insurance, taxes and cost of renewals § 26	144,000	34.0
5. Total	$422,880	100.0
Which divided by 12,760, the average H. P., § 20, gives the following :		
Cost of steam power per H. P. per year on basis of delivering 20,000 H. P. maximum and an average of 12,760 6. H. P. for every day in the year		$33.14
Cost of steam power per H. P. per year on above basis if 5 per cent. of the original cost of plant be charged for dividends and $1 per H. P. added for general expenses, 7. § 18, 33.14 + 3.60 + 1.00 =		37.74
Cost of steam power per H. P. per year on above basis if 10 per cent. of the original cost of plant be charged for dividends and $1 per H. P. added for general expenses, 8. § 19, 33.14 + 7.20 + 1.00 =		$41.34

§ 22. The cost of coal is made up as follows: By reference to § 20 it will be seen that 15,000 H. P. of boilers out of 20,000 must be shut down daily for periods varying with the demand, and it is considered that it will require an amount of coal equal at least to the average consumption for one hour during regular operation, to maintain banked fires, overcome radiation, and bring the fires to average working condition when they are again put in operation. The total daily H. P. hours in line 4, §20, is therefore increased 15,000 and multiplied by 309; the horse-power hours for the 56 holidays, line 6, are then added to the same; the sum multiplied by 1.25 pounds of coal per H. P. and by one mill per pound and one-twelfth added to the whole for friction, which gives the result written in line 1, § 21.

§ 23. The labor cannot be distributed accurately until the variations of loading are developed practically. On any definite basis, such as is assumed in § 20, the watches could be arranged so that there would be little loss of time, but in practice there would be a variation of load at the same hour on different days. For instance, with the electric lighting part of the load, the demand would vary with the weather; with the cable or electric railroad portion of the load the demand would be greater on particular days and seasons, and vary also somewhat with the weather, so to be provided for unexpected demands, there must be a surplus of labor. Such surplus will be assumed at 20 per cent. for the 14 hours of reduced power per working day, shown in § 20, lines 2 and 3, equivalent to labor for 28,000 H. P. hours per day, or 8,652,000 H. P. hours for 309 days. Adding only 10 per cent. for 56 holidays gives $6{,}720{,}000 \times 1.1 = 7{,}392{,}000$ H. P. hours. Adding both to the total H. P. hours, § 20, viz.: 111,780,000, gives a total for the year of 127,824,000 H. P. hours, which at $0.00027 per H. P. per hour (= $5.40 ÷ 20,000) easily derived from § 13 gives:

Cost of labor per year	$34,512
Cost of superintendence per year, from § 13	13,140
Total for labor and superintendence per year as written in line 2, Table II., § 21	$47,652

§ 24. The cost of labor and superintendence above is $100 \times \$47{,}652 \div 60{,}444 = 78.83$ per cent. of that required for full operation throughout the year shown in § 8, although the average power developed is only 63.80 per cent., § 20.

§ 25. The cost of supplies and regular repairs, line 3, will be

somewhat greater proportionally than for continuous operation, and is estimated to be 70 per cent. of the similar costs given in § 8, $105,120 × 0.70 = $73,584, which is written in line 3, § 21.

§ 26. Evidently the interest, insurance and taxes given in line 4, § 8, are not modified, and the percentage allowed for renewals is so small as not to materially affect the result, so the amount given in line 4, § 8, is repeated in same line of Table II.

§ 27. The presentation in Table II. will give a fair idea of the prices it would be necessary to secure on installing a large steam plant to furnish power in various quantities to consumers on the premises, or to apparatus for transmitting power to the same, the costs of which transmission are not included. The costs at which the power can be sold under certain specified conditions, as stated in lines 7 and 8, § 21, are the only features that directly interest consumers of power.

§ 28. A large proportion of the power in manufacturing establishments is used only 10 hours per day, so this investigation would not be complete if it did not include a presentation of the cost of steam power generated with large units for 10 hours per day. Such an estimate is made in Table III., the explanation of the items being given afterward as heretofore.

§ 29.

TABLE III.

SHOWING THE COST OF STEAM POWER ON THE BASIS OF GENERATING 20,000 H. P. CONTINUOUSLY FOR 10 HOURS PER DAY FOR 309 DAYS IN THE YEAR.

			Per cent of total cost.
1.	Yearly cost of coal, § 30	$92,656	30.6
2.	Estimated cost of labor, §31	27,198	9.1
3.	Estimated cost of supplies and regular repairs, § 32	37,080	12.3
4.	Estimated interest, insurance, taxes, and cost of renewal. § 33	144,000	48.0
5.	Total	$300.334	100.0
	which divided by 20,000 gives the following:		
6.	Cost of steam power per H.P. per year on the basis of delivering 20,000 H. P. continuously for 10 hours per day for 309 days in the year	15.17	
7.	Cost of steam power per H. P. per year on above basis if 5 per cent. of the original cost of plant be charged for dividends and $0.75 per H. P. added for general business expenses, § 18.....15.17 + 3.60 = 18.77; 18.77 + 0.75 =	19.52	
8.	Cost of steam power per H. P. per year on above basis if 10 per cent. of the original cost of plant be charged for dividends, and $0.75 per H. P. added for general business expenses, § 19.....15.17 + 7.20 = 22.37; 22.37 + .75 =	23.12	

§ 30. The yearly cost of coal, line 1, above, is obtained by computing the coal for 11 hours per day, for reasons explained in § 22 and making the calculations explained in the latter part of § 12 for $309 \times 11 = 3399$ hours in the year.

§ 31. The labor would be occupied 309 working days, and, say, one half the holidays, § 20. The cost of labor for 337 days of 10 hours or 3370 hours, at $5.40 per hour, § 13 = $18,198. Two assistant engineers could be dispensed with, compared with § 13, thus reducing the cost of superintendence to, say, $9,000 per year. The sum of these two quantities is written in line 2 of Table III.

§ 32. The cost of supplies and repairs is estimated at the rate of 0.6 mill per H. P. hour as per § 14, $20{,}000 \times 3090 \times \$0.0006 = \$38{,}080$, as written in line 3, Table III.

§ 33. The amount written in line 4, Table III., is the same as for the two other cases. The cost of renewals should apparently be reduced as the machinery operates less hours, but the percentage allowed for renewals is very small and should be increased for the other cases rather than reduced for this. Moreover, renewals are made more frequently on account of new discoveries or changes in business than from the actual wearing out of the apparatus.

§ 34. The prices given in the lines 6, 7 and 8 of Table III., § 29, will best compare with those carried familiarly in the mind. The minimum cost derivable from the paper in TRANSACTIONS for 1893, above referred to, is for coal at $2.24 per ton and ten hours per day, $22.31 per H. P. per year. This should be compared with $18.77 in line 7, of Table III., as the previous calculations provided for 10 per cent. interest and dividends, as is provided in lines 4 and 7 jointly in Table III., but not for general business expenses. The difference is $3.54 per H. P., corresponding to a saving of 15.87 per cent. by generating the power on the larger scale.

§ 35. The quantities in the previous paper above mentioned were augmented here and there, so as by judgment to try and approximate the various losses incident to average practice, though insufficiently to show the results of such practice in some locations. The prices herein given, are as low as it would be safe to expect with very careful management of a very large plant. The comparatively small difference in result is due to the influence of the constant cost shown in line 4 of the several tables.

It forms 26.3 per cent. of the total cost for 20,000 H. P. every hour in the year, Table I., § 8; 34 per cent. for variable power, 20,000 H. P. maximum, 12,760 H. P. average day and night, and rises to 48 per cent. for 20,000 H. P. during 10 hours of the ordinary working days in a year. The cost of coal is respectively 43.4 per cent. 37.3 per cent. and 30.6 per cent. of the total cost for the same three conditions. The fixed charges also increase greatly the cost of water power, as the writer has had occasion to call to the attention of parties engaged in these large hydraulic enterprises.

§ 36. It should be borne in mind that if water power or power derived from water be sold on a 24 hour basis, but can only be utilized during 10 hours per day, the cost of the water power direct or derived should be compared, not with the cost of steam power on a 24 hour basis in Tables I. or II., but with that of steam power on a 10 hour basis in Table III.

§ 37. It should also be borne in mind that all these estimates provide for fixed expenses, such as interest, insurance, taxes and cost of renewal, and that in comparing the prices above given with the cost of water power, similar fixed expenses should be added to the price of such power, based on the cost to the consumer of installing the water power or the mechanism through which the power is derived. For instance, manufacturers located on the canals of large water power companies necessarily build their own head and tail races and wheel-pits, and install the gates, screens, turbines and means of transmission for utilizing the power. This when well done, in many locations costs as much as to install a steam plant, so the fixed annual charges for this item alone would be $5.00 to $7.00 per H. P., which together with cost of labor and supplies, must be added to the cost to be paid for the water power in order to compare with the cost of steam power as presented in the tables of the writer.

§ 38. When power is electrically transmitted, the consumer is generally required to pay for the electric motor, the general means of transmission therefrom and some incidentals. The cost of this work, together with the portion of the building and even of the real estate occupied should be considered in the same way as has been done above, and at least 10 per cent. of such cost, together with actual costs of labor and supplies, added to the tendered price of net power delivered, in order to compare the cost of power obtained in this way with the cost of steam power

shown in the various papers of the writer, which are written on the basis that a manufacturer should receive a profit on the money expended in plant as well as that expended in his business. If interest is left out in one case it should be in the other, and it is already included in the tables.

§ 39. The last column of the several tables, furnishes a ready means of eliminating either of the items of cost desired. For instance, in Table III., which is on a 10-hour basis, we find in line 4 that the "estimated interest, taxes and cost of renewal" is 48 per cent. of the total cost, which cost to the parties owning the power is in such table $15.17 per year, line 6. The cost of steam power per H. P. per year from large units for 10 hours per day, without considering the above items, is therefore only

$0.52 \times \$15.17 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \$7.89$

which is the cost to be compared with the price of power from an external source when the items above referred to are excluded in each case as they are in the popular discussion of the subject The similar cost from the estimate in the TRANSACTIONS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS above referred to is $22.31, § 34, less $(3.31 + 7.17) = 22.31 - 10.48 = \ldots$ $11.83, the difference $3.94 being due principally to the relative sizes of the plants considered in the two cases.

DR. EMERY continued:—Anticipating that inquiry will be made as to the cost of power from Niagara, at my request Mr. Foster has been kind enough to ascertain the facts. The Cataract Construction Company have offered undeveloped water power at this place for $10 per H. P. per year. They have also offered power delivered from the top of a shaft here for $13 per H. P. per year, and power delivered at the terminals of a dynamo here for $18 per H. P. per year. The power is evidently intended to be "24-hour power." For the first case, the lessees must evidently construct their own hydraulic work, involving the turbines and wheel-pits and hydraulic connections from the same to the head canal and the tail-race tunnel. For the second price, evidently the parties must pay the entire cost of transmission, starting from a vertical revolving shaft, upon which may be placed at their expense a dynamo or ordinary mechanical means of transmission. For the third price the parties must pay the cost of an electrical transmission starting with current delivered at the terminals of the dynamo.

Discussion.

Prof. Wm. A. Anthony:—I would like to say just a word in regard to that last, in relation to what they propose to charge for power here. As I understand it that charge is based upon the maximum power that the party proposes to use, which puts a very different aspect upon the case from what it would have if it were power delivered by the meter. I have seen some of the contracts that are drawn up by the Cataract Company, and in them they state expressly that the charge is for the maximum power, and the amount of power is to be occasionally determined by some indicating instrument, and if at any time the maximum power used by the consumer exceeds the power for which he has contracted, then a new contract will be made on the basis of the largest amount of power he has used at any one time during the previous term. Now, as Dr. Crocker showed yesterday, the power that a man uses on an average is not more than 50 per cent. at most, of the maximum power that he uses. You will see that in paying for 200 H. P., for instance, at these rates, he really uses only about 100 H. P.; and in comparing what he would have to pay the Cataract Company for his power, you should compare it on that basis; that is, he is paying for 200 H. P., while if he were generating the power himself he would count 100 H. P. as the average. I suppose that in Dr. Emery's estimate of the cost of power, it would be the power actually used that would cost so much per annum, and in the case of a man using 100 H. P. actual, that estimate would show what it would cost him if he generated it for himself.

Dr. Crocker:—It is rather strange, but I was about to bring out a point similar to that spoken of by Prof. Anthony, only looked at in precisely the opposite way. I notice that Dr. Emery in the paper considers average power and not total power, that is, he divides by 12,760 and not by 20,000. In other words, he obtained the cost of actual power delivered, as Prof. Anthony has just said. Now, it seems to me that the ordinary manufacturer, developing his own power, does the opposite and divides by 20,000. In other words, he divides by the maximum and not by the actual power which he gets, and that is the way the very low figures for the cost of power generated in the ordinary factory are obtained, I think. The manufacturer knows in a general way the total cost of his power, although I think he often leaves out many items, and is apt to consider that all the cost of power is for coal, and he forgets incidental expenses, repairs, etc., that should be included, and which put together aggregate a large amount. But assuming that he does know what the total cost is, I think he usually divides by the total capacity of his engine, getting thereby a very low result per H. P. In other words, assuming that he has a 100 H. P. engine and that it cost him $3,000 a year. Now he is very apt to divide the $3,000 by the 100 H. P.

and get the low price of $30 as the cost per horse power per year. As a matter of fact that engine, as Prof. Anthony says, probably has not been developing more than 50 H. P. on the average throughout the year. Therefore he should have divided by 50 and obtained the higher price of $60. I think the notion that power costs very little, is due partly to leaving out items of expense which should be included, but chiefly to dividing by the total power of an engine, or the nominal power, instead of by the actual power developed throughout the year. What Prof. Anthony says would imply that you should add a good deal to the $18.00 named in Dr. Emery's paper in order to compare it with the ordinary figures. My idea is that you should take the ordinary figures, and reduce them considerably before you could compare it with the $18.00. It amounts to the same thing, but it is not exactly the same idea. His remarks imply that the ordinary manufacturer is accustomed to consider the actual power developed, in which I do not fully agree with him.

PROF. ANTHONY:—My remarks were based upon two or three factories that I happened to know of, where the parties keep a pretty good record of the power that they are using, by indicator diagrams taken occasionally along through the year. They take diagrams perhaps every day, and keep a sort of average in that way of the power that they use during the year, and divide by that average power, as indicated by those diagrams. That is the way the price has been obtained in three or four manufacturing establishments of which I happen to know.

THE SECRETARY:—While I am not altogether familiar with the subject under discussion, there is one thing that occurs to me in connection with our various publications in the TRANSACTIONS, and that is that there has never been any reference to the use of mechanical stokers. In talking with some of the European engineers, I have been told that they are quite commonly used over there; but so far as I know there has never been any reference to the advantage or the disadvantage of using them, or as to their practicability in this work, where the tendency is toward the greatest economy; and it appears to me that on this occasion it might be well to make some reference to that in connection with this paper by some of the gentlemen who are familiar with the subject.

MR. OBERLIN SMITH:—I want to ask the question whether the price which is mentioned for power from the Cataract Company is based on a minimum of 20,000 H. P., or whether they will sell smaller quantities at those same rates; because, if they will, the comparison would not be fair with a 20,000 H. P. steam engine. A small unit of steam power, say 1,000 or 2,000, would, of course, cost considerably higher than Dr. Emery's estimate for 20,000; so that we ought to know, in discussing this comparative power of water and steam, whether we are talking about the same sized unit.

DR. EMERY:—It seems necessary to answer the questions so far raised at once. The paper under discussion refers to my previous INSTITUTE paper on the same subject which was based on 500 H. P. units. Questions as to the cost of the power with smaller units, or in engines of different kinds are not raised in the present paper, but anticipating that they would be in the discussion, I have ascertained that, using 500 H. P. units operated 10 hours per day on working days, for coal at $2.24 per ton, delivered in front of the boilers as in the present paper, but with other conditions the same as in the former paper, the cost of steam power would be approximately as follows:

Non-condensing engine	$29.90	per	H. P.	per	year.
Condensing engine	23.81	"	"	"	"
Compound engine	22.86	"	"	"	"
Triple compound engine	22.31	"	"	"	"

The last price is the only one stated in the present paper and is in section 34 compared with the corresponding cost with large units, viz: $18.77 per H. P. per year (line 7, Table III.,) the difference, $3.54 per H. P., corresponding to a saving of 15.87 per cent. by generating the power on the larger scale. It will be recollected that in the former paper, by assuming different prices for the different engines, the increase of the interest practically balanced the saving in coal, so that there was very little difference between the better classes of engines of different kinds when all the costs were considered. The final results have proven to be remarkably near those that have been obtained in actual practice by others who have communicated with me. In that paper the extensions were not made on the basis of the best experimental results, but allowances were included which augmented the costs so as to approximate actual practical conditions. In the present paper the extensions were made on the basis of the lowest quantities derived from experiment, which it is considered can be repeated in practice under careful management.

MR. OBERLIN SMITH:—Can you tell me what the smallest amount of power is that the Cataract Company will furnish at the prices that were mentioned?

DR. EMERY:—I do not know. I anticipated that general questions as to the cost of power here would arise and was therefore prepared to answer them. There are gentlemen connected with the company here who may be happy to give details of the kind requested.

MR. SMITH:—In order to have a definite unit of a smaller size I will ask the gentlemen directly, what they would charge for 1,000 H. P.—about what increase over the figures given in this paper? I will ask what per cent. will have to be added if they take on a basis of 1,000 instead of 20,000; that is, roughly speaking, how much more would it cost?

DR. EMERY:—For steam power, comparing the prices in the

present and former papers, the difference is only $3.54 per H. P. For engines of different kinds, the difference will be increased by amounts corresponding to the increase of yearly cost which I have already read. As the discussion appears to drift toward general questions instead of being confined to the special one considered in the paper, I will write the costs of power for engines of different kinds on the blackboard with the permission of the President.

MR. SMITH:—In the meanwhile, will any one in the room say whether the Cataract Company proposes to furnish at the price mentioned as small a quantity as 1,000 H. P., or, if not, about how much more it would cost in that small quantity?

MR. JOSEPH WETZLER:—I believe the Carborundum Company has closed a contract for 1,000 H. P. to begin with.

MR. PETER WRIGHT:—The Carborundum Company pays $20,000, I understand, and the prices quoted, $10, $13 and $18, are for a minimum of 10,000 H. P. That is my recollection from an article in the *Electrical World* a few months ago.

MR. SMITH:—Then on this 1,000 H. P. they pay about $20 instead of $18, which they would have to pay for a larger amount, is that the idea?

MR. WRIGHT:—That is my understanding.

MR. SMITH:—Then we appear to be working on a basis in this locality of 1,000 H. P. at $20. That is, delivered at the Cataract Company's house, is it not, at the dynamo terminals? Now we have something to compare with steam power, when we find out what that will cost here in units of 1,000 H. P.

MR. WRIGHT:—In looking over these figures of Dr. Emery's, I am a little surprised that there is no provision made for depreciation. I suppose that Dr. Emery did not overlook that, but I am a little surprised that no provision is made. I have made a simple calculation here, allowing for depreciation four per cent. on a plant costing practically a million and a half. The added cost would be $2.88 per H. P. per annum, and I would like to ask Dr. Emery why that amount is not fair to be added. It seems to me that in an undertaking of this magnitude it would be only wise business policy, to say the least, to make some provision for depreciation, and four per cent. allowance would be about right, I think.

DR. EMERY:—This discussion is covering so large a field that with your permission, Mr. President, I will answer these questions as they arise. The depreciation is already considered in the tables given in the paper, but under a different name; it is called "cost of renewal." There are two ways of treating the matter. One is to depreciate the property on the books every year, and the other is to consider that a certain amount is withdrawn from profits and put at interest in a sinking fund to renew the plant at the end of a definite period. If we depreciate four

per cent. of the original cost yearly, such cost will be wiped out entirely in 25 years. If the depreciation is four per cent. of the cost shown on the books for the previous year, the reduction will be much slower. If, however, four per cent. of the original cost be put at interest yearly, the resulting sinking fund will equal the original cost in 15¼ years. It will be seen, therefore, that the method adopted makes a great difference. It is not necessary to deposit four per cent. of original cost yearly for renewals; three per cent. is ample even under modern conditions, where plants are changed constantly on account of new conditions, or change of business, since at six per cent. it corresponds to renewal in 18½ years, and at five per cent. in 19½ years.

MR. OBERLIN SMITH:—The cost given for the triple compound engine is, I presume, for a 1,000 unit?

DR. EMERY:—It was 500 H. P. or multiples of that sum, and does not change very much, so that that is near enough for your calculation.

MR. SMITH:—$22.31 then, covers everything? That is, it buys coal here and pays interest, depreciation, incidental expenses and everything else, so they could actually farm out this power at $22.31 if they had that given engine——

DR. EMERY:—I will ask you to yield one second, if you please. That is on a 10-hour basis. I intended to mention that. It is a very important consideration. As you will see, those prices are not as high as they would be, on a basis of 24 hours, but most of our power is run for 10 hours, and the figures given above are on that basis.

MR. SMITH:—Assuming that a concern could only run 10 hours, as most factories can placed here,—assuming that they are a little way off from the terminals of the dynamos where the loss on the line would only be small, that they have got to put in the transformers at their own expense and get the power in shape to use, the price would be about $20.00; so that on the 10-hour basis it would seem as if it cost the same here on a 1,000 H. P. unit to buy this water power from the Cataract Company, or to have the steam power. But on the large unit, the water power would very likely be somewhat cheaper, the electric water power, or whatever you call it; therefore, on a 24 or a 15-hour basis, should a factory want to run that long in a day, the water would seem to be the cheaper, because you have to pay just as much for 10 hours water as you do for 24, as I understand it.

DR. EMERY:—It seems necessary to recall attention to the fact that if power be furnished a manufacturer at the terminal of a dynamo, he must run his own line to the motor, put in the motor and connect it at his own expense in a building belonging to himself, and then put a man in charge of it. The motor, with a mere local line and other work required will cost, say, $30.00 per H. P., which at 10 per cent. makes $3.00 a year fixed expenses.

The man's time cannot be neglected, so on this basis $3.00 per H.P. per year, plus the whole or a portion of the man's time must be added to the cost of power delivered electrically in order to compere the same with the cost of steam power as given in this paper. This is not all, for if the power is sold at electrical terminals, miles away, interest on the cost of the main transmission line and a charge for transmission losses must also be added.

MR. SMITH:—I should say that that is a very high estimate; to add half, making it $30.00 instead of $20 per year—so simple a machine as a motor is, and so little attention as it requires and so small as the repairs are.

DR. CROCKER:—I think that Dr. Emery's last statement is not exactly fair to the electrical system. The object of my paper this morning was, to show that given a steam engine in a factory, the cheapest and best way to get that power to the machines was to put in a dynamo, conductors and motor. Consequently we have to compare the steam engine in the man's factory with the electrical power in the Niagara power house. That, as I understand it, is the true comparison. Now the question is,—How shall we get that power to the machine tools in the two cases? That is too difficult a problem to go into here, but it was certainly the object of my paper, and, so far as I have heard, there were no exceptions taken to the general conclusion that the best way to get the power to the machine tools was to turn it into electricity and turn it back again into mechanical power; and in this particular case we have an advantage over the case considered by me, because in the latter we have to supply a dynamo also. Here we have the electrical energy given to us, and we would simply have to supply the line wires and motor, the factory presumably being located near to the power house, or at a reasonable distance, for 2,000 volts pressure. It would probably be necessary to introduce step-down transformers, as we would not be likely to use 2,000 volts in the motors at the factory. But that item of expense would not be large. I do not think it is fair to consider that the simple steam engine cost is the total cost of the power for driving factories. The system of distribution must be included.

DR. EMERY:—These tables are not yet fully understood. The statements made by Dr. Crocker are not disputed, but the interest on the cost of the steam engine is already in the price given for steam power; 10 per cent. of the original cost being added in line 4 of each table for interest, insurance, taxes and cost of renewal. Therefore, there must be added to the price that is charged for water power 10 per cent. of what it costs to utilize it. If the electric current is received from a local company, it may, as stated, possibly be utilized for a local outlay of $30.00 per H. P., when $3.00 per H. P. per year should be added to the price of the power and more or less, as the cost is greater or less, and to this should be added the cost of labor as explained,

also the cost of repairs and supplies, which I omitted to mention a moment ago, though considered in the tables. If, however, the price for power is fixed at, say, $18.00 at electrical terminals miles away from the city where the power is to be utilized, the cost of a general electric transmission must also be considered, and as this would be too great to be undertaken by small consumers, it must necessarily be constructed by a company which must add its own interest, repairs, maintenance and profit, thus increasing the cost to the consumer correspondingly.

MR. SMITH:—I think, Mr. President, we are trying to compare entirely different things which depend upon how you look at them. Now if we assume, with Dr. Crocker, that we are going to run a factory or a shop with motors all over it, as in all probability will often be the case in the future, then the electric power will have the advantage, because, as he says, Dr. Emery will have to add his dynamo, short line wires and the motors in with his steam plant. But if the calculation is based rather upon the old-fashioned way of running, with a lot of shafting and belts all over the mill, in such case Dr. Emery would be right. So before we know which is right we must know which system we are going to run the mill on. As a practical matter this power delivered here in factories will in some cases be used electrically, like it is in the Reduction Works, where they do not want any rotary motion; but where it is wanted as rotary motion there is no doubt, in this electrical age, that much of the machinery would be run, individually or in groups, by motors, and therefore we would have to have them anyway in addition to the steam engine; so it still gives some advantage to electric power. The calculation I made roughly just now, bringing them about equal for a 10-hour day, only allowed the cost of the short line, which would not be much (and the loss in it would not be much), and the cost of the transformers to get the big voltage down, but I did not allow for the motors scattered around the factory, and it is very proper to leave them out, because in a modern system we would have to have them anyhow, even with a steam engine.

MR. LEWIS B. STILLWELL:—I should like to ask Dr. Emery a question in regard to the estimate on page 471, Table II, in which the "cost of steam power per H. P. per year on basis of "delivering 20,000 H. P. maximum and an average of 12,760 H. P. "for every day in the year" is calculated to be $33.14. Is there any allowance in that for the cost of attendance upon and maintenance of electrical machinery, which would be necessary to put such a plant upon a fair basis of comparison with the plant of the Cataract Construction Co. here at Niagara Falls, for example?

DR. EMERY:—There is no such estimate as that, Mr. President. There is an estimate for the cost of an engine to make the wheels go around which is to be compared with that of an electric motor to make the wheels go around. If, as it has been urged here, the cost of a motor is not to be charged in one case

then the cost of an engine should not be charged in the other, and in the case previously referred to it is necessary to make the comparison as in § 39, not with steam power at $22.31, but with such power at $11.38. We start in both cases with a shaft in revolution either with a steam engine or with power electrically transmitted.

MR. STILLWELL:—That replies to my question, and states the point to which I wish to call attention. In the paper which Dr. Emery read a year or two ago, I think the estimate of the cost of steam power was based upon the assumption that we were to drive a line shaft, and apply to that line shaft 500 H. P. It ought to be noted that when this is taken as the basis of comparison we should compare the cost of the hydraulic machinery in the electric-hydraulic plant, and stop at the end of the hydraulic machinery. It is not fair to the electric-hydraulic plant to take the 500 H. P. unit from the engine on the engine shaft, or a 20,000 H. P. unit on the line shaft, and compare this with electric power delivered at the terminals of a generator. Dr. Emery explains that the 20,000 H. P. is meant to make the wheels go around—the ordinary wheels which we have in factories and mills. It seems to me it ought to be brought out clearly that, in order to make this comparison exactly fair, we should add to the cost of the steam power, as we calculate it, the additional cost representing the interest on the investment in the electric generators, and attendance, depreciation, and other charges properly chargeable against the electric plant. In order to bring the 20,000 H. P. steam plant to a basis fairly comparable with the electric plant in the power house of the Cataract Construction Company to-day you would have to purchase generators. You cannot take 20,000 H. P. on a shaft and compare it with 20,000 H. P. at the terminals of a generator, ready to be transmitted and distributed.

MR. B. J. ARNOLD:—The point brought out by the last speaker, I think, is a very essential distinction. The actual work we have to do with power in large cities is such that it is necessarily divided into small quantities or units. We have very few power users who will require power in 1,000 H. P. units, so that the real comparison to be made is between the cost of power delivered at the work by the transmission plant in, say, 100 H. P. units, or even less, and the cost of power in similar quantities produced by steam. Now power in these quantities costs in our best steam plants to-day about one cent per H. P. hour delivered on the engine shaft. Reducing this to its equivalent in electrical energy, we get a kilowatt hour on the switchboard ready for distribution to our small motors for about one and one-third cents in the larger plants and not over one and three-quarter cents in the smaller ones. It seems then that if we can buy power produced by this transmission plant delivered at the terminals of the small motors in our individual factory machines for less than one and one-third cents per kilowatt hour, that it would pay us to buy it. Unless

we can do this, we can put in a steam plant and operate our factories cheaper by steam.

One point brought out by Dr. Emery's paper is the necessity of operating large steam units if we are going to put in a central station to distribute power. The cost of labor is reduced very largely, as the size of the unit increases. He has mentioned the fact that it would be desirable to connect one or more units in some manner so that a large steam engine might operate a number of electrical units. I think this is very desirable, and if the shafting could be eliminated, it would reduce the cost of labor to probably 20 per cent. in a 5,000 H. P. station over what it would be if we had a large number of small steam engines to operate. Another thing which I understand from the contracts that the Cataract Construction Company are making with consumers is, that they require the consumer to contract and pay for a certain amount of power, and not to exceed that quantity. This has been found very objectionable in city practice. In other words, if the consumer exceeds for a short time the total amount of power his contract calls for, he is violating his contract and is compelled to make a new contract covering the increased amount, even though he does not expect to use it. The power should be put upon a meter basis, or upon some dynamometer basis, so that he would pay for the actual power used. I think any power user will concede this, but the difficulty is to get the power companies to execute a contract on this basis.

As to the question of mechanical stokers, which was mentioned by the Secretary. I have had more or less to do with this class of work, and while I find most of the mechanical stoker and patent furnace companies willing to guarantee to evaporate 1,000 pounds of water for from 11 to 13 cents, by the use of bituminous slack coal, which is about eight cents less than the ordinary boilers evaporate water for, when using bitumious run-of-mine coal, I find that the cost of maintaining these stokers and their appurtenances almost equals the saving in fuel in small plants, so that there is but very little object in using them, except in the large power stations where, owing to the great distance that the coal has to be handled, mechanical coal conveying plants can be put in, which will deliver the fuel directly into the stokers, thereby effecting a large saving in labor and making the stokers more economical and desirable than hand firing.

MR. HARRY ALEXANDER:—Mr. Stillwell touched upon a point that until then I was totally at sea about. If, as Dr. Emery mentions, the power is to be rented at the wheels, how, in small parcels, is this power going to be transmitted? If it has to be transmitted to generators, and from those on to motors, including the line and the motors as well, I do not think it a fair comparison at all. If the Cataract Construction Company is willing to rent at $10 per H. P. at the dynamo terminals, and, as Dr. Emery mentions, for $11.83 per H. P. where the wheels turn

around, the advantage lies immediately, as far as the price per H. P. is concerned, with the electric power. That is, you have only to construct your line, furnish your transformers and your motor, whereas in small parcels with steam transmission you would have to hitch on to the line in whatever manner suggested itself, which would include belting to the mechanical shafting and the dynamo, etc. This dynamo naturally would have to be placed at the power house. Now the question arises,—Is there room for that? If there is room, has that room been figured on? The matter that I was at sea upon was, how that power was to be transmitted, and if it was to be transmitted by mechanical power, as I thought, why then this question arises of belting to the shafting and the dynamo and the room for the dynamo and the increase in the size of the building, etc. The cost of that has, I think, been left out of Dr. Emery's calculations.

DR. EMERY:—Again I have to make an explanation, as the discussion has drifted to questions not raised in the paper. I have many times been asked to work out the theoretical cost of steam power derived from large units. I anticipated that questions would arise in the discussion as to smaller units of power, and have therefore placed upon the blackboard some results taken from the former paper, but the units even in that case are too large to cover some of the ground discussed here. Mr. Arnold has hit the nail closely on the head by the statement that in ordinary practice a horse-power hour costs about one cent. That rate for a year of 3,090 hours would make $30.90 a year, and looking at the figures on the blackboard we find that the price given for non-condensing engines in my previous paper is $29.90 per year for 500 H. P. engines, which is too low for small engines and conservative for large ones. This is a little less than one cent per H. P. per hour, and for more economical engines the cost would be a little less than $\frac{8}{10}$ of a cent. All the expenses incident to 75 H. P. developed in a non-condensing engine ought to be obtained for $1\frac{1}{4}$ cents per H. P. per hour, and this cost would run down to $\frac{8}{10}$ of a cent with larger powers and better engines.

We are now prepared to discuss the general question: For what price can be installed and operated a steam engine for an establishment requiring 75 H. P. and upward, and what is the yearly cost of such power in comparison with power derived from electrical transmission? As stated, the cost of steam power in plants not smaller than stated would vary from $1\frac{1}{4}$ down to $\frac{8}{10}$ cent per H. P. per hour, which includes everything required to make the shaft revolve. If lights are required in the building, a dynamo must be used, but ordinarily only for that purpose. For power delivered electrically, as Mr. Arnold has very clearly stated, such power must be transmitted from the dynamo here, for instance, to the point at which it is to be used, in Buffalo or elsewhere, and in general sent out again to a motor in an establishment where the power is to be used, and the net power must

be delivered for 1¼ cents per kilowatt hour in order to compete with steam for power. The more exact figures given above are equivalent to 1⅜ cents for kilowatt per hour for the higher limit, and this price falls to 1 1/16 cents for better engines available from 100 H. P. and upward. For lighting and power in small quantities, more may be charged, say about 2 cents. The greater convenience of power derived from electricity would give some advantage, but the cost must be balanced in the way I have already several times pointed out. I think I have made the matter clear, but will be happy to go over it again if desired.

MR. ALEXANDER:—I would like to put this question to Dr. Emery: In what manner is it proposed, even for short or long distances, to transmit this mechanical power for industrial and manufacturing uses? This is a point I do not as yet fully understand.

DR. EMERY:—I propose to erect a steam engine and boiler directly in the building where the power is required.

MR. ALEXANDER:—Then the idea of comparison is only to large units, not units of 1,000 H. P.?

DR. EMERY:—The paper refers to large units, but small ones are now being discussed. The question is, whether we shall put in steam plants where the work is to be done, or an electric plant to utilize electric current transmitted through a wire.

MR OBERLIN SMITH:—We all, I think, have a great deal of confidence in Dr. Emery's calculations on steam power, and I should freely accept them rather than work them out myself. I have no criticism to make on the paper itself whatever, but in making this comparison, the question arises,—are we right in comparing so large a unit as 20,000 H. P.?—because if we get this great plant Dr. Emery has considered, we have the wheel going around, but who of us here knows what to do with a revolving shaft that has 20,000 H. P. stored in it? How are we going to distribute it for ordinary operations? How many belts, pulleys, shafts and journals are required to distribute it and divide it up, as Mr. Arnold speaks of? For ordinary purposes, outside of driving a city full of cars, or something of that kind, we want this power split up, and we have to allow for the expense of getting a steam power mechanically and distributing it among our shafts and belts. And then it is not the question of starting a great plant here to rent out power generated by steam. We would have to have special means of transmission to neighboring factories to get rid of 20,000 H. P.—cables, very long shafts, or someting of the sort, and here is where the electric power seems to have the greatest advantage, as it has an infinite capacity for being divided up as much as we choose. When we have 20,000 H. P. at the terminal of the generators, we can run an ordinary wire, or cable of wires out, with hardly any expense for short distances, and divide them up in as many branches as we like; so that really, after all, this discussion ought to have

taken place on a much smaller unit, on perhaps 100 H. P., as the factories in question would, under ordinary circumstances, naturally, have their own engines, one 500, another 100, another 50, and so on. We ought, therefore, to take a small unit for comparison, thus bringing the steam power expense higher. And then the question comes up,—how is the power going to be used in the factory? If, as I said before, we want shafting and belting and the old-fashioned methods generally, then steam may be nearly as cheap; but if we want the new-fashioned method of having motors, then we would have to have them with the steam engine, and the electrical power seems to have the advantage. I suppose the fact is that the Cataract people will really put this price that we are talking about just a little lower than steam, so as to tempt people to come. It does not need to be a great deal lower, naturally, as a merely commercial matter which regulates itself.

MR. STILLWELL:—It seems to me that Dr. Emery has given us all we can ask in the way of estimates on the cost of steam power, and has now stated clearly what is intended by his estimates. The discussion has rather drifted away from the paper. His paper last year made an estimate of the cost of steam power on the shaft in units of 500 H. P. That is a valuable estimate. I am sure that electrical engineers and others who have had occasion to figure on the cost of power have used it many times; but in using it, some care has to be taken to be sure that we are making the proper kind of comparison. If we take the 500 H. P. delivered to a shaft in Buffalo, we should obviously in making the comparison take care to include every item in the cost of a hydraulic and electric plant necessary to deliver at a line shaft located in Buffalo the same amount of power. Now the paper to-night makes a calculation of the cost of a steam plant to develop 20,000 H. P. This is more than we have occasion to use in one unit, except in the central station. All that we have to do in using that calculation as a basis of comparison with the cost of hydraulic and electric transmission is to be sure that we compare with it only the cost of the hydraulic machinery ready to deliver to the electrical machinery, or any other machinery, 20,000 H. P. I am sure that Dr. Emery's calculations have been very valuable and useful. The results may or may not be realized. They at least indicate an ideal toward which steam practice is tending. The results as they are stated, taken as an ideal, are, I think, encouraging to hydraulic and electric transmission in general. The estimate to which I first referred (viz.:—$33.14 per H. P. per year, on an average of nearly 13,000 H. P. in a 20,000 H. P. maximum), is one against which almost any hydraulic plant can certainly compete. If you add to this estimate the cost of the electrical plant necessary to put this 20,000 H. P. steam plant on the same basis as the hydraulic-electric plant ready for transmission, the figures will be raised considerably, and I am very sure that the electric and hydraulic

plants, assuming that high load factor, can in general compete successfully.

MR. NELSON W. PERRY:—It seems to me that one feature of this question has not been touched upon to-night. That is, suppose we had a project to establish a plant ultimately to be expanded to a given larger capacity, would it pay us to take a water power and through that water power employ that capacity, or would it be more economical for us to do it by steam, assuming certain conditions of cost of coal and other necessaries? Now, in a water power plant, it is usually necessary to develop in the beginning a very much larger proportion of its utmost capacity than there is any immediate demand for. Take the plant here. It was necessary, in order that a single horse-power should be available, to tap the river above the Falls by means of a tunnel. At the start of any enterprise of this kind we may be sure of an immediate demand for but a very small portion of the maximum capacity. We know that in a given water power where there are, say, 10,000 H. P. available, we can count upon an immediate sale of only, say, 1,000 H. P. We have to develop that 10,000 H. P., however. Dr. Emery has called attention to the great influence upon cost of the fixed charges. While we are selling that 1,000 H. P. with an available 10,000 H. P., we are paying fixed charges on 10,000 and charging only for 1,000 H. P. If on the other hand we have coal and are projecting a plant of equal size, we put in, say, two 500 H. P. units to supply the existing demand and pay fixed charges in the beginning only on that, and then when the demand increased we would put in another unit, and so on, so that we would have an output of nearly all our plant from the time we started. I think that among engineers that point is not so often overlooked, but among those who have not given the subject attention it is overlooked a great deal. They assume that where they have a 10,000 H. P. water power, and it costs so much to develop, interest, etc., that the cost per H. P. to them is that cost divided by 10,000, whereas it is that cost divided by 1,000. Now, in a growing project of that kind, where it is necessary to make a very large investment with the expectancy of an increasing demand for the output, it must be uneconomical at first to start a water power. Under most conditions a steam plant would be much more economical, for the reason that we can increase it as the demand increases, and pay fixed charges only on a plant actually earning to nearly its fullest capacity.

ALLAN V. GARRATT, of Boston:—I am inclined to take exception to what the last speaker has said, for this reason,—if we start out to build a 10,000 H. P. hydraulic plant, the conditions are not often the same as we find here at Niagara Falls. I could quote perhaps a dozen cases of plants in the far West, where peoples' ideas are apt to be large, and where they wish to lay out for a comparatively large plant ultimately, but realize quite fully that the present demands for power will be small. It is self-evident

that if you wish to come out with a very large plant at some time which you hope will arrive in the future, it is not necessary to build the whole plant on the 10,000 H. P. basis. There is a certain portion of your construction that may be necessary to be completed from the first, but those water powers as a rule are avoided by investors, which make this necessary to any large degree, and such construction can usually be put in which will take care of such a load as can be obtained in the immediate future, without making such an extortionately great investment. On the other hand, it is undoubtedly true that in almost any water power plant the first development must be larger than in a steam plant. That is undoubtedly true. I never have known a case to be otherwise. But the difference is not so great in favor of the steam plant as the last speaker would seem to intimate. Now, under the comparatively high heads which obtain throughout a large portion of the United States, especially the growing portions of the United States, as for instance on the eastern slopes of the Rocky Mountains, and on the western slopes of the Sierra Nevada, and the Cascade ranges, we find water powers tumbling down through deep canyons in such a way that you can take off a portion of that water and carry it down through a steel flume, which is a common practice in that country, and investment in wheels and heavy masonry at the base, and all that sort of thing is carefully looked after at the start, and they go right on with the development in proportion to the output of the plant. It is not necessary in the majority of cases to put in an enormous construction at the start which must not be touched while your plant is being loaded up to the maximum point which you intend to reach. So that the investment can in a very great number of cases be kept very small, and the investment increased as the earning capacity of the plant increases. And you will find if you look over the history of water power development in the United States, you will find that water power properties, which require enormous investments in the start, have not been touched unless it is seen that a very large earning capacity can be gotten from them at present. But let us take for example, well, the Rainbow Falls across the Missouri River, which comes into my mind at present. There is naturally a very good water power, capable of giving, I should think, in the natural effect of the river at that point, perhaps, 50,000 H. P., as a rough estimate, and at the present time they are using about a twentieth of that. Now the construction at that point is such that it is just right, it is thoroughly adapted to what they want at the present time and in the immediate future, and is such that they can can keep on developing it, just as when people build a steam plant and so arrange it that the steam plant can be increased up to any load they are going to have, without making an extortionate investment at the beginning. So I think it is hardly fair to the water power to lay it down as a broad and fundamental fact that when you

start out with the ultimate intention of developing power in very large amounts, your investment must be for the ultimate output of your plant from the very start, and that if you intend to have 1,000 H. P. developed at once, that you must make the price of the 1,000 H. P. you are going to sell on the basis of the total fixed charges on 10,000 H. P., because it is not anything of the kind. Neither is it fair, of course, to say that you divide the fixed charges on 10,000 H. P. by 10, and call that the price on 1,000. The history of water power plants, so far as my experience has gone, has led me to see that the operating expense and fixed charges get less and less as you go up in size of plant, until it finally reaches the minimum. This is not so absolutely unreasonably as one might be led to suppose, and on the other hand we know that very many steam plants are so poorly laid out, that you do not get the proportionate decrease in fixed charges and operating expenses as the load increases.

DR. EMERY:—The principal points have been so thoroughly considered in detail, that there is little to say in closing. The most important question yet remaining seems to be that raised by Dr. Crocker and Mr. Stillwell, to the general effect that the fixed expenses due to an electric transmission plant should be added to those of the steam plant, for the reason that 20,000 H. P. could not be utilized at any one place, and that a means of transmission and sub-division is necessary. This is true in regard to 20,000 H. P, but not true of moderate sized plants where 25 to 100 H. P. and upward is required. Dr. Crocker urges that an electrical system is the cheapest way of distributing power even from a shop engine to the various tools, but it would seem extreme to urge this system for plants of 100 H. P. and less, particularly for those already established. Water power transmitted electrically to large cities will for a considerable time be principally required as a substitute for steam power already installed. In such cases evidently the cost of the installation of the electric plant, together with its operating expenses, should be added to the cost for which the power is delivered. Even if it is desirable to employ largely the system of electric motors operating individual tools, or clusters of tools, as referred to in Dr. Crocker's paper on the subject, this is a question of shop economy which does not affect that of bringing the power to the shop. The former, with old plants, has nothing to do with the case, and with new installations the electric plant can for moderate powers at least be charged to shop transmission and not to the power. In the majority of cases, therefore, the only logical method of comparison is to start with a revolving shaft. Without disputing the broad proposition of Mr. Stillwell as well as Dr. Crocker, that power from a large steam plant must have means of transmission to the several kinds of work in detail, this is also true of large steam plants already installed. The units of the 20,000 H. P. plant are only 2,500 to 5,000 H. P., which are in frequent use, and the elaborate lines of

shafting, gearing, belting, etc., from such units to rolling mills, flouring mills, cotton manufactories, etc., are necessary and expensive but form a part of the internal transmission, not that of bringing the power to the works. An electrical transmission in the factory is only a substitute for this, and should be charged in the same way. We grant, however, that there is much in the suggestion, as applied to a very large steam plant designed to distribute light and power in opposition, we may suppose, to proposed distributions of power derived from water, but this is not the question at issue. In developing a water power, the question is how such power can be most economically transmitted and distributed, and the same question exactly would arise in relation to a large steam plant. From our present lights, the natural answer is,—put the water or steam power into electric energy as soon as possible, and this will be available at the points of transmission both for lighting and power purposes by the use of proper apparatus. The cost of such transmission and distribution might be so great as not to warrant carrying out the enterprise either for water power or for steam power. The question may be asked, then: What is the value of an estimate on a 20,000 H. P. basis as given in the paper; steam plants on land are unknown that require such a power locally; it is only a steamship that requires it? In response I may say that, curiously enough, the popular mind wanted what may be termed a bottom price for comparison. I have been asked to make such an estimate by many. I was asked to make it by the general officers of the Cataract Construction Company. They wished to know the cost of power on this large scale developed in a plant in the outskirts of Buffalo. I responded that I did not think that was what they wished to know, and asked permission to tell them what my views were, and finally was requested to do so. I trust there is no breach of confidence in making this statement, but will not try to remember my reply. I, however, say now that *the basis of comparison seems to me to be the relative cost of power delivered in desired quantities to the several consumers as compared with the cost of steam power on the premises.* Mr. Foster has since examined the subject for the company. His investigations show that steam power costs in Buffalo much more even than stated in my original paper in 1893, which at the time was considered unnecessarily conservative by many parties. I do not think the details of Mr. Foster's determination have ever been submitted for criticism, but if the results are accepted, the parties attempting a solution of the problem should consider what the results would be if the manufacturers of Buffalo should adopt means for securing economy in steam power.

Let us examine what this discussion has developed in this line. If one H. P. delivered at the terminals of a dynamo here for $18 per year can only be utilized 10 hours per day, or, say roughly, 3,000 hours in the year, the power delivered at the dynamo

terminals here will cost $\frac{6}{10}$ of a cent per H. P. per hour. Some power will be sold out of business hours, but the maximum power must be charged for all the time, so with a low power factor, as is probable, the average cost cannot be greatly varied. By Mr. Arnold's short rule, modified in both directions by the figures I have given, the power should on the average be delivered by steam engines in Buffalo, with all charges of interest on plant, attendance, repairs and supplies added, for about one cent per H. P. per hour. Upon this statement of the problem, who will undertake to "bell the cat," put in the transmission line, connect with the several stations there, or build new ones, send out this power locally, furnish the motors and connections and deliver power to the several consumers at these prices? Can it be done by any other parties than those who wish to receive $18 per H. P. at the dynamo terminals here?

The President announced the appointment of the following members as a Committee on Resolutions: B. F. Thomas of Columbus, O.; B. J. Arnold of Chicago, and W. J. Hammer of New York.

[Recess until 10 A.M.]

A paper to be presented at the Ninety-ninth Meeting of the American Institute of Electrical Engineers, New York and Chicago, September 25th, 1895.

[ADVANCE COPY. SUBJECT TO REVISION.]

PHASING TRANSFORMERS.

BY CHARLES S. BRADLEY.

On account of the large number of single-phase plants in existence which were built for lighting, and with no thought at the time of running motors from these systems, it has seemed to the electrical engineer very necessary to produce a single-phase motor. Many talented men have labored and studied upon this subject, and, so far, the results have not been at all satisfactory.

During the last few years the rapid progress of the polyphase motor has been the only success. The evolution of electrical art seems to be toward the production of apparatus which shall make all systems mutually convertible; so that we may be able to convert the phases produced, into a greater or lesser number; starting with a generator of three phases, we shall be able to produce from it two or one. Again, generating two phases, we shall be able to convert it into three phases or one. Again, starting with a single-phase generator, we shall be able to convert it into two or three phases.

The polyphase motor is so good as to need but very little, if any improvement, but this is so familiar to the INSTITUTE, that I need not go into details. I think the time is not far distant, when we shall be able to fill out with the alternating currents, any engineering problem that may be required of us. We will be able to take old plants and modify them to do any work which may be necessary. One of the important links to round out the art, seems to be the phasing transformer, so that we can take a single-phase alternating current, and convert it into polyphase of any desired number.

I have chosen for my work, the conversion of single phase to

three-phase, because the three-phase motors which we have been able to construct, give us very much less trouble than the two-phase. In a series of experiments, I have found that the two-phase motor would run at a number of speeds, especially when supplied with current from a phasing transformer. I supposed the trouble arose from harmonics, but of this I am not certain. The triphase motor never has given us any of this trouble. These experiments, however, were carried out before the transformers had been refined; and, now that we are getting more perfect results, I think it is very probable that we could return to the two-phase motor and get much better results than when first tried. The following is a description of an arrangement of condensers and cores to produce polyphase and single phase alternating cur-

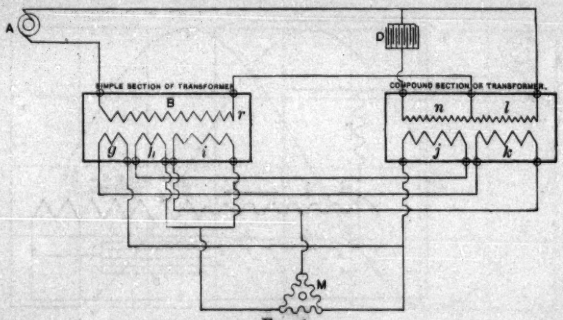


FIG. 1.

rents. Many different arrangements of condensers and inductances have been tried, and all have failed to keep their phases at a working relation, except the one I am about to describe.

A diagram of the phasing transformer and connections with the generator and motor, will be found in Fig. 1, A being the generator, B the simple section of the transformer, D the condenser, and M the motor; r, primary of the simple section of the transformer, n and l, primary of the compound section; g, h, and i, secondaries of the simple section of the transformer, and j and k secondaries of the compound section. The primary of the simple section of the transformer is in series with the compound section, and condenser. By the proper adjustment of capacity and inductance, the magnetic flux in the core of the compound

section is approximately 90 degrees in phase behind the simple section, then, in order to get three phases from the two, I resort to resultants in the secondaries: g and k constitute one phase, h and j a second, and i the third. The essence of this invention rests in the arrangement of the compound section of the transformer and condenser. There are, undoubtedly, several ways of explaining the theories involved in this device, and most people would prefer the mathematical description, but, as I did not hit upon the invention by that method, I shall follow in the explanation, the same method of reasoning as I used to arrive at the result. In order to explain the theory involved in this, refer to Fig. 2, in which A is the generator, E, the inductance, D, a condenser or capacity, l and n represent the leads to the inductance E, and

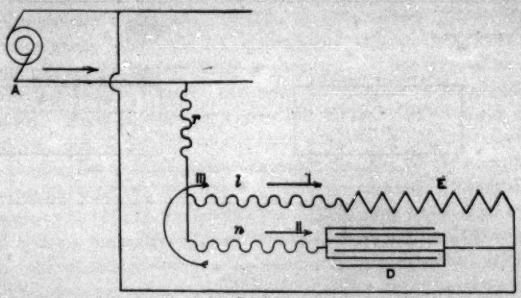


FIG. 2.

to the capacity D. If the generator is generating an electromotive force in the direction of the arrow, Fig. 2, a current will flow through the lead l and the inductance E, as represented by the arrow prime, and through n into D, in the direction of the arrow second, as indicated by the curves in Fig. 3; that is, during the rise of the electromotive force through the machine from the point, o, to the top of the wave at p, the current will flow in parallel into or through the inductance E, and the capacity D, Fig. 2. As soon as the wave of the electromotive force commences to decline from the point p, the condenser will begin to discharge and the current flowing from it, will be in the direction of the arrow third, Fig. 2. Also, at the same time, the inductance will discharge its energy by a current in the direction of

arrow third, so that the current represented by arrow third will cross the zero line at point *t*, Fig 3., or is delayed by a time equal to 90 degrees. Thus, we see that the current represented by arrow third will be lagging in its time period considerably behind that in the lead *r*, represented by curve *o–p*. Now, if we wind the lead *l* and the lead *n*, upon an iron core as shown in Fig. 4, in opposite directions and of the same number of turns, and have the inductance E bear a proper relation to the capacity D, so that the currents represented by arrow prime and arrow second shall be equal, no magnetic flux will be produced in the core during the rise of the potential of the machine from *o* to *p* on the curve, but during the fall of the electromotive force of the machine, and during the discharge of the inductance and condenser which is rep-

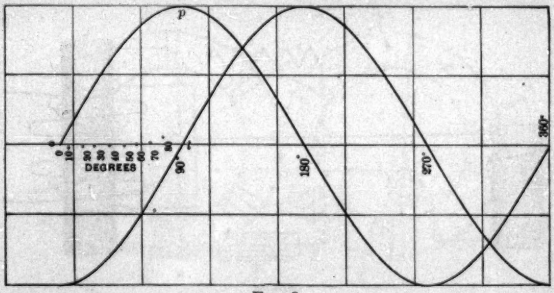


FIG. 3.

resented by arrow third, Fig. 2, the currents flowing through *n* and *l* will be in series and flowing in the same direction; consequently, the magnetic flux will be approximately 90 degrees later than it would be if charged directly from the machine. I have represented in Fig. 2, a section of lead by *r*, and it will now be clearly seen that the current in the lead *r*, will have a phase difference from the combined or resultant phases in the leads *l* and *n*. Furthermore, a current in the lead *r* will be in lead of the electromotive force of the machine, because the inductance and the condenser, previously described, cut off the flow of the current before the machine has reached the zero point, and when the lead *r* is placed upon an iron core as shown in Fig. 4, it has a tendency to lag, which counter-balances the lead and leaves the main line

current somewhere near in phase with the E. M. F. of the generator.

Please refer now to Fig. 4, where the leads l and n are wound in opposite directions, and completely interlaced upon the iron core L, the generator, inductance and capacity being indicated by the same symbols as in previous figures. The lead r is here wound upon the second iron core, which constitutes the primary of the simple section of the transformer as shown at B, Fig. 1. In reducing to practice and applying the transformer to an induction motor, we find that the inductance E, can be dispensed with, as the apparent inductance produced by the motor furnishes all the lag necessary; and, it will be noted, that in Fig. 1, the extra inductance which we used in our first experiments, is left out of the combination. The lead from the simple section of the trans-

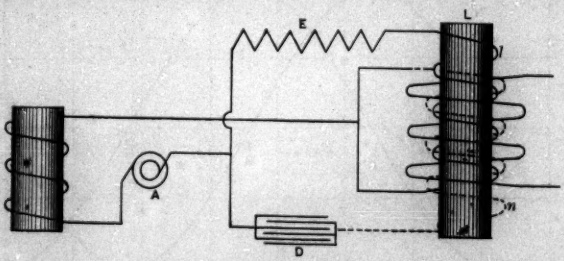


FIG. 4.

former, it will be noted, goes to the center of the compound section. This diagram does not represent the true condition of the compound section, for the winding n and l are together, or, as before mentioned, interlaced upon the core. The magnetic flux in the two sections of the transformer are approximately 90 degrees apart. The secondaries are therefore wound each partially upon the two cores, so that the three resultant phases may be produced from two, this being in accordance with Mr. Fred. S. Hunting's invention for changing two phases to three. For the description of this I will quote Mr. Hunting's own words, and the plan is in Fig. 5.

"If P^1 and P^2 represent two primary circuits supplied respec-
"tively with alternating currents differing in phase, or disposed
"in any other suitable manner so that the fluctuating magnetic

"impulses developed in the cores M^1 and M^2 differ in time, then "the secondary currents developed in circuits s^1 and s^2, will differ "in time period. If other circuits as s^3 and s^4, be so arranged "that part of their convolutions will enclose one magnetic core "and part another, there will be developed in these circuits a "resultant current due to the combined action of both magnetic "cores, and this current may be given any desired degree of phase "displacement with reference to the current in primary coils P_1 "and P^2, accordingly as the number of convolutions surrounding "the respective cores is varied. For example, if, as shown in "circuit s^4 an equal number of convolutions is placed around each "core, then there will be developed in circuit s^4 a resultant cur-"rent having its phase half way between the phase of current in

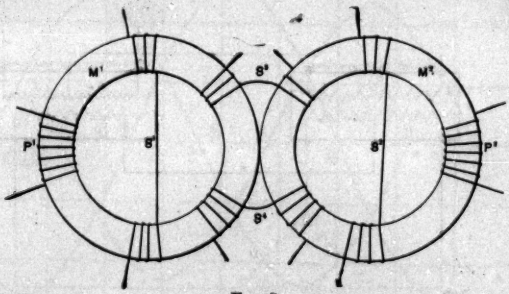


FIG. 5.

"coils P^1 and P^2. If the number of convolutions on the two cores "vary in the proportion of three to two, and be joined together "as indicated by the coils s^3, the resulting current produced by "these coils will be closer in phase to the current flowing in P^1, "providing the larger number of convolutions be placed as indi-"cated in the diagram upon the magnetic core controlled by coil "P^1. Thus, by varying the relative proportions of the two coils "inclosing the two magnetic circuits, a resulting current of any "desired phase displacement with reference to the phase of coils "P^1 and P^2 may be developed. It will thus be seen that by means "of two magnetic circuits or cores in which magneto-motive "forces differing in phase are developed, we may produce any "desired number of currents of differing phase, and may produce

"a definite degree of phase displacement, and the resultant cur-
"rent may in any case be shifted closer to the phase of magneto-
"motive force in either core, by increasing the inductive influence
"of said core upon the circuit carrying the resultant current.

"In the organization shown in the diagram, we will have four
"secondary currents developed from the primary coils P^1 and P^2,
"and assuming that the currents flowing through these coils
"differ in phase all of said secondary currents will differ in
"phase."

Mr. Scott's invention for changing two phases to three, may also be used, and is shown in Fig. 6. Making the resultants in this manner by means of the secondary windings contributes also

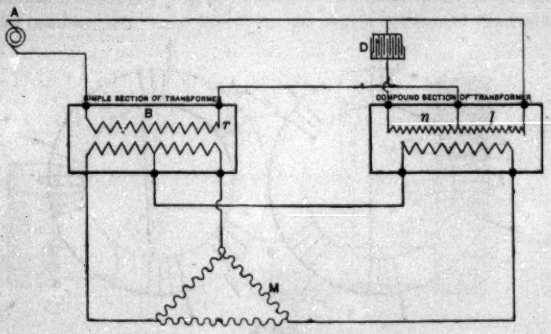


FIG. 6.

to steadiness of phasing. If desired, two secondaries having a proper two-phase relation may be used on the motor.

The experimental work in which I have been greatly assisted by Messrs, Hulse and Chapman, has occupied a long time and has passed through a great many stages. The results represent a great deal of patience, and we have chased the phases from zero to 180 degrees, back and forth, until there is a well-worn path between these two points, but finally we have a set of beautiful results, and the electromotive force curves will be found in Fig. 7, taken from the transformer, in connection with a half-horse power motor, running at full load, and Fig. 8 gives the current curves of the same. This motor gives powerful starting torque, and it gives me pleasure to show it to you here in operation. I want to

bring to your attention one feature of the compound coil used in combination with the condenser, which will be found in Figs. 9 and 10. If we suppose a direction of motion as shown by the arrow and the current in the condenser branch leads by 90 degrees, which is represented at *b*, and the current in the inductance branch lags by 90 degrees as indicated at *c*, and the wires carrying these currents are wound in opposite directions upon the core, we will have a resultant current, which is represented by extension *d*. Increase of load, changes the phase relation of the individual branches, but not the resultant secondary, and this is explained by reference to Fig. 10, where a 75 degree lead, and a

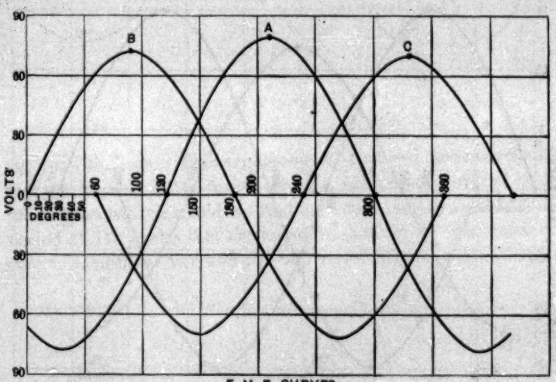


FIG. 7.

75 degree lag are represented by the respective branches, and as the branches are wound in opposite directions, we find that when *b* is turned over, it becomes a lag of 105 degrees, and the resultant of 75 degrees and 105 degrees again produce 90 degrees lag, and the value again represented by the extension *d*, the value of the current is slightly less, but its resultant phase is the same as is represented in Fig. 9. This explains the steadiness of phasing which we are able to obtain. This may be explained by another method of diagramming as is shown in Figs. 11 and 12, where curve *a* represents the fundamental current, curve *b*, Fig. 11, a lead of 90 degrees, curve *c* a lag of 90 degrees, and then *b*

being turned over, unites with c to produce the resultant d, which is 90 degrees in lag of fundamental curve a. Now, in referring to Fig. 12, where the fundamental current is again represented by a; curve b represents a lead of 75 degrees, and full line curve c represents a lag of 75 degrees; then, when curve b is turned over in the windings, as shown in the dotted line, the coils being wound upon the same core, a resultant effect is represented by the curve d, which is 90 degrees in phase from fundamental curve a. Thus we see by increase of load, which tends to decrease the lead

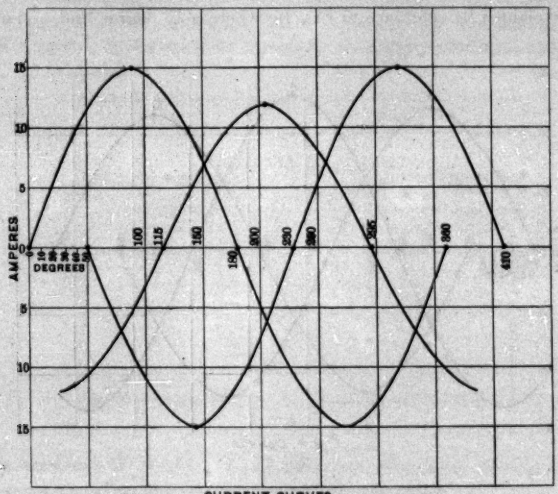


FIG. 8.

of the condenser circuit, and also decreases the lag of inductance circuit, our resultant is still in the same phase relation to the fundamental current.

The power factor is found to be very good. The current in the main line, feeding the transformer varying from 10 degrees lead at full load, to 35 degrees lag at no load, and the motor at starting produces the same effect as when working at full load, so that we have very good phasing for starting and full load, as well as a good power factor, it being 82 per cent. even at light loads,

and the probability is that we will have very much better results upon larger sized transformers.

The condenser in this combination fills two very important functions, first assists in the phasing, and second prevents the

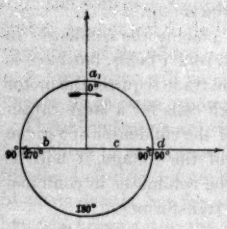


FIG. 9.

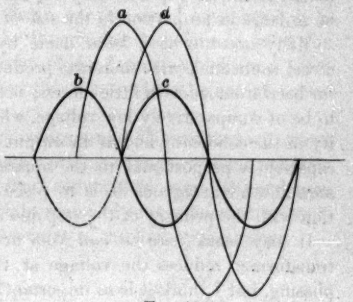


FIG. 11.

lag upon the line. This arrangement does not prevent the idle currents flowing in the motor circuits, and the secondaries of the phasing transformer, and we find in small motors with the high period of 140 cycles that the apparent energy in the motor circuits is sometimes two and one-half times the apparent energy in

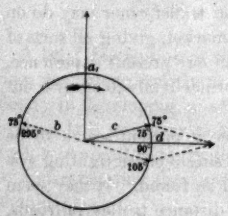


FIG. 10.

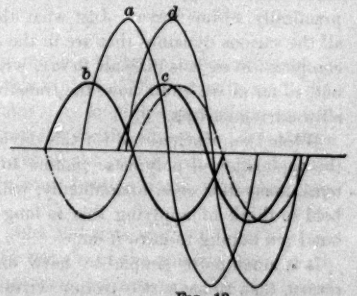


FIG. 12.

the main line. The capacity of condenser for a one-half horse-power motor when 1,000 volts are supplied to the transformer is about 2.4 microfarads. Our condenser for this size, without connections, occupies a space of a cube four inches on each side, and

capable of enduring 3,000 volts, or a factor of safety of four, as the voltage on the condenser is about 700. Of course, it will be understood by those familiar with the designs of induction motors, that it is impossible to design a small motor with small power factor, as the air-gap necessary for mechanical construction has to be so large in proportion to the size of the motor.

Many attempts have been made by placing the condenser in direct connection with motors to produce rotary fields, but have so far been attended with little success; as the trade requires the motor to be of comparatively low voltage, which calls for a large capacity in the condenser, and as the output of the condenser of a given capacity is proportional to the square of the voltage, it will be seen how advantageous it is to place the condenser in combination with the primary of the step-down transformer.

It may seem trite to call your attention to the fact that the transformer reduces the voltage at the same time it does the phasing, but I think it is so important that I wish particularly to emphasize the fact. It is also of great importance that the device has no moving parts.

Upon reference to the cuts showing the curves obtained of the electro-motive force and current, it will be readily seen that they are all of true sine form. The current for this work was obtained from a 75 K. W. Slattery alternating machine. This machine has a surface winding on the armature, and, therefore, gives practically a sine wave. Just what the transformer may do on all the various dynamos that are in the market, giving all sorts of complex waves, it is difficult to say, with our present experience, but, so far as we know now, the transformer tends to smooth out all the irregularities.

While the principal use for this device at present seems to be the application of polyphase motors to single-phase lighting systems, many new ones, undoubtedly, will be found. It may seem bold to think of applying this to long-distance trolley railroads, but I am hoping to have it done.

It is much more simple to have one trolley wire with track return, than to have two trolley wires which would be required by the direct application of polyphase systems. A large amount of power requires either a large current or high voltage, in order that the resistance of contact of whatever device is used to make connection to line need not be too great. As viewed at present, it seems as if the alternating current must be used for this work.

If so, and unless the traffic is extremely frequent, it will take many more transformers, if they be placed along the line, than if the transformation is made upon the car or locomotive; because the transformers along the line having no trains or cars near them, would be idle.

If the voltage is stepped down on the car or locomotive, it is just as economical to do it by the phasing transformer, with the exception of the added weight of condensers, which for a 1,200 H. P. locomotive will be about two tons, and this is not of consequence on so large a power.

These condensers are very compact and efficient, and will stand from three to four times their working voltage, without puncturing the dielectric. I am sorry I cannot show you the condenser in all its details, but for certain reasons I cannot do so at present, but will present it to the INSTITUTE at the first opportunity.

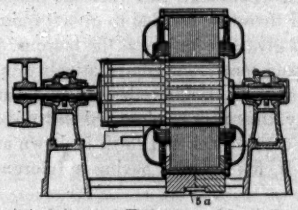


FIG. 18.

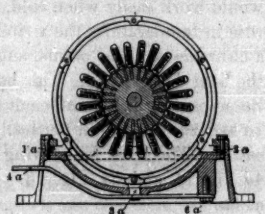


FIG. 14.

A brief description of the motor may be in order, although it does not belong strictly to this subject. We met with much difficulty in developing a motor for so high a periodicity as 140 cycles. It is necessary to keep the density so low, and it is always such a temptation to try to get all the power from a given piece of apparatus, that they are always heating much more than they should.

With a large number of poles and slots, we found that any use of wide bars in the armature was out of the question, for the eddying currents in the copper were too serious. *We also looked for difficulties which we never found.* At times we thought the heating was due to higher harmonics produced from the phasing transformer; but the fact is, we never found any, unless it was in the experiments upon the two-phase motor. As mentioned before, the waves are all of the true sine form.

Cuts of the motor are shown in Figs. 13 and 14, the rotary field being the exterior or stationary part, and the secondary or induced constituting the armature. The armature is composed of two sections, or practically two armatures end to end upon the same shaft, one of the armatures having a low resistance winding and the other a comparatively high resistance; the field is placed over a high resistance for starting, and shifted by means of a lever over the low resistance, when it has nearly attained speed. Of course, this arrangement is for securing the starting up of the motor, and has nothing to do with the phasing transformer, and the motor might have rings for connecting the starting resistance to the armature and operate quite as well. The sliding of the field gave trouble, as the air-gap has to be small, and the play at the sides (noted 1*a* and 2*a*) allowed the armature to strike against the field, and when a tight fit was made, which would work easily when cold, it would stick fast when the motor rose in temperature; the writer therefore decided to give it quite a clearance at these points, and give it a guide at the bottom of the field shown at 3*a*. This being central and comparatively thin, the expansion is not sufficient to cause sticking, also the guides at 1*a* and 2*a*, being thin vertically, they may fit close and still slide easily. The lever for moving crown back and forth is shown at 4*a* Fig. 14, and 5*a* Fig. 13. It fits loosely, having a fulcrum at 6*a*.

WESTERN UNIVERSITY OF PENNSYLVANIA.

ALLEGHENY, PA., APRIL 24th, 1895.

PROFESSOR EDWIN J. HOUSTON, CHAIRMAN COMMITTEE ON INCOMPLETED CONGRESS WORK,
PHILADELPHIA, PA.

DEAR SIR: In reply to your request for a statement of the results obtained by me in regard to the work on standards of light and illumination, I would make the following report.

1. *Secondary Standards:* — The result of my work on incandescent lamps has shown that a set of two incandescent lamps, mounted so as to invariably have the same point turned toward the photometer spot, as faced it when the lamp was originally standardized, and worked at the same voltage as that at which the standardizing was done, can be used with very considerable accuracy for secondary standards. As mentioned in a previous report, one lamp is used for the photometric work, and the other is used as a check, and when the reference lamp has been burned a total of 200 hours, the set is to be discarded. The curve of fall of candle-power with life can be used for making corrections.

2. *Primary Standards:*—Work on the acetylene standard mentioned in a previous communication has been prosecuted under difficulties, as I had to make my experiments with barium carbide, and could, up to a week ago, obtain but small quantities of the gas. I have since been able to obtain a sufficient quantity, and have made numerous experiments.

So far, my attention has been given to the best means of keeping the gas at a uniform pressure, and on the best pressure to use. I have devised a convenient and satisfactory method of accomplishing the former, and enclose a drawing of the apparatus at present in use. As regards the latter, I find that a tolerably high pressure gives better results as regards constancy, than a low one, the pressure at present used being 12 inches of water.

By reason of the results obtained by Captain Abney, who showed that a flat flame gives a much more even illumination than a round one, I have been using a flat flame. The experiments so far made show a very constant illumination, and this without using a chimney.

The experiments about to be made will be on the following points:—*a*. effect of impurities in the gas; (*b*) best means of obtaining flat flame; (*c*) possibility of accurately reproducing standard absolutely, by using slot of definite size and definite mode of generating and using.

I may say that an appropriation of $800.00 has been made by the university for the purpose of making these experiments.

In conclusion, I would state that the acetylene standard appears to me to have the following advantages, provided that further experiments show it can be duplicated successfully.

1. *Use of definite chemical compound*, on the line suggested by Mr. Kennelly at the meeting of December, 1893. Even if different specimens of calcium carbide should be of different degrees of impurity, there is no reason to doubt but that these impurities can be absorbed, and pure acetylene left.

2. *It is self-contained*, the only materials used being calcium carbide and water, and no connection to gas pipes are necessary.

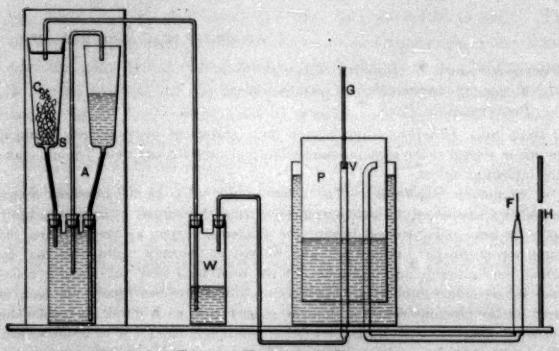


FIG. 1.—Fessenden's Report.

A. Generating Apparatus.
C. Carbide of Calcium.
S. Strainer.
W. Wash Bottle.
P. Gasometer.
V. Regulating Valve.
G. Guide Rod.
F. Flame.
H. Slot.

3. As the substance burned is of a definite chemical composition, and the dimensions of the slot and all the apparatus is capable of being accurately defined in terms of length and pressure, it seems to afford a method of obtaining an absolute standard.

4. *The light appears to be much whiter* than ordinary gas, which is a point of considerable importance in a standard. No exact spectro-photometric measurements have as yet been made, however.

I remain, very truly yours,

REGINALD A. FESSENDEN.

[Presented to Council May 21st, 1895, and ordered to be printed in the TRANSACTIONS.]

"The work contains much valuable information, which is here published for the first time, and owing to the simultaneous sessions of the different sections of the Congress, many of the papers are new, even to those who attended the sessions."—*Electric Power.*

Now Ready

PROCEEDINGS

OF THE

International Electrical Congress

AT CHICAGO, 1893.

Published by the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

PRICE, $3.00.

This volume is the only complete and authorized edition of the proceedings of the most important electrical gathering ever held in America.

It contains the official report of the

CHAMBER OF DELEGATES,

and the frontispiece is a reproduction of the only group negative of its members in existence.

The papers read before the Congress are fully illustrated, and with the verbatim discussions, form a book of great historical and technical value. It contains 522 pages, and its publication was under the supervision of a special Committee of the Congress, and a similar Committee appointed by the Institute.

Among the contributors and participants in discussions appear the most distinguished names known in electrical science.

The book will be sent by express or mail prepaid on receipt of the price strictly in advance.

Cloth, $3.00.
Paper uncut, $3.00.
Half Morocco Cloth Sides, $4.25.

Address,

American Institute of Electrical Engineers,
26 CORTLANDT ST.,

Telephone 2199 Cortlandt. **NEW YORK CITY.**

"A full history of this interesting and important congress of electricians, and a publication of the many papers presented to it by some of the foremost electrical engineers of the world."—*Engineering News.*

"The report of the Chicago Electrical Congress constitutes a volume which has a distinct value, not only as a record of what was accomplished at that important meeting, but as a memento of a gathering such as will probably not be brought together for many years to come."—*Electrical Engineer.*

"Of very great interest and value to all who have to do with electricity."—*American Machinist.*

"The proceedings of the INSTITUTE have acquired so high standing that any of their publications may be pronounced a sine qua non in every scientific library. As a matter of course, the present work represents the highest grade of publication in its own line. We may note that this volume is largely given up to alternating current work, and thereby the tendency of the day is indicated."—*Scientific American.*

EDWARD P. THOMPSON, M. E.

PROF. WM. A. ANTHONY,

TEMPLE COURT, - - NEW YORK.

United States and Foreign **Patents**, Electrical Specifications, Expert Advice and Testimony.

American Electrical Works,

Manufacturers of

BARE & INSULATED ELECTRIC WIRE, CABLES, &c.

Providence, - R. I.

DAY'S KERITE

DAY'S KERITE

Highest Grade of Insulation for

Electric Wires and Cables.

—GRANTED:—

Two Highest Awards World's Fair, Chicago, Ill., 1893.

W. R. BRIXEY,

SOLE MANUFACTURER,

203 Broadway, - New York.

J. E. HAM,

General Agent.

EXPERIMENTAL AND MODELWORK,

Electrical Apparatus and Fine Machinery,

Special Tools, Patterns, Gear Cutting, Specialties, Repairs, Etc.

E. V. BAILLARD, 106 Liberty St., N. Y.

TRANSACTIONS WANTED.

I have orders on file for volumes 3 and 4 (1886 and 1887) Transactions A. I. E. E., wanted by new members and libraries to complete their sets. The following prices will be paid for copies in good order.

Volume 3, - - - - - **$2.**

Volume 4, - - - - - - **$3.**

Address, RALPH W. POPE, Secretrry.

McINTOSH, SEYMOUR & CO.

AUBURN, N. Y.

—BUILDERS OF—

Engines FOR ALL **Electrical Purposes.**

THE AMERICAN BELL TELEPHONE COMPANY,

125 MILK STREET, BOSTON, MASS.

This company owns Letters-Patent No. 463,569, granted to Emile Berliner November 17, 1891, for a combined telegraph and telephone, covering all forms of microphone transmitters or contact telephones.

Information Regarding Transactions.

The monthly parts distributed to members and subscribers during the year, are not intended for binding, but simply for the use of readers, as the work of the Institute progresses.

After printing the monthly, the papers and discussions are revised, repaged, and the sheets for the annual volume printed from the corrected type, and laid aside till the close of the year. As the index is made for the volume and **not** for the monthly parts, the complete volume sent at the end of the year becomes the permanent record. Upon its receipt the monthly parts are superfluous. They may be returned to this office at our expense, as there is a continual demand for separate copies of papers.

RALPH W. POPE, Secretary.

COPPER WIRE TABLE.

This table gives the WEIGHTS, LENGTHS and RESISTANCES of cool, warm, and hot wires of

MATTHIESSEN'S STANDARD CONDUCTIVITY,

for both Brown and Sharpe (A. W. G.) and Birmingham Wire Gauges (B. W. G.)

It was prepared by the Institute Committee on Units and Standards, personally revised by the individual members of the Committee, and issued with the October, 1893, number of the TRANSACTIONS, forming a part of Volume X.

Mailed separately, price 10 cents.

RALPH W. POPE, Secretary,
26 Cortlandt Street,
New York City.

Contents of Vol. XII. 1895, as far as Published.

CATALOGUE OF MEMBERSHIP. ON THE UNITS OF LIGHT AND RADIATION. By Alexander Macfarlane. THE BEST METAL FOR FIELD MAGNET FRAMES. (Illustrated.) By Alton D. Adams. No. 1, January. RAIL-BONDING, AND ITS BEARING ON ELECTROLYTIC CORROSION. (Illustrated.) Communicat on by Geo. P. Low. NOTES ON RECENT ELECTRICAL ENGINEERING DEVELOPMENT IN FRANCE AND ENGLAND. By H. Ward Leonard of New York. No. 2, February. A METHOD FOR PREVENTING ARMATURE REACTION. (Illustrated.) By Harris J. Ryan and Milton E Thompson. No. 3, March. RESONANCE IN ALTERNATING CURRENT LINES. (Illustrated.) By E. J. Houston and A. E. Kennelly. UNDERWRITERS' RULES. By W. A. Anthony. No. 4, April. OBITUARY.—George M. Phelps. LEONARD ON EUROPEAN ENGINEERING. (Chicago Discussion.) RYAN AND THOMPSON ON ARMATURE REACTION. (Chicago Discussion.) HOUSTON AND KENNELLY ON RESONANCE. (New York Discussion.) ANTHONY ON UNDERWRITERS RULES. New York and Chicago Discussion. PRELIMINARY REPORT INDEXING COMMITTEE. REPORT OF COUNCIL, SECRETARY, TREASURER AND TELLERS. No. 5, May. PROPERTIES OF FUSE METALS WHEN SUBJECTED TO SHORT CIRCUITS. By W. E. Harrington. THEORY OF THE GENERAL ALTERNATING TRANSFORMER. By C. P. Steinmetz. LOCATION OF GROUNDS IN ARMATURE, FIELDS, ETC. By Clarence E. Gifford. THE SUBSTITUTION OF ELECTRICITY FOR STEAM IN RAILWAY PRACTICE. By Dr. Louis Duncan. COMPOUNDING DYNAMOS FOR ARMATURE REACTION. By Prof. Elihu Thomson. ELECTRIC POWER IN FACTORIES AND MILLS. By Dr. F. B. Crocker, V. M. Benedikt and A. F. Ornsbee. SOME FEATURES OF ALTERNATING CURRENT SYSTEMS. By C. P. Steinmetz. SOME OBSERVATIONS ON A DIRECT CONNECTED 300 K. W. MONOCYCLIC ALTERNATOR. By Profs. D. C. Jackson and S. B. Fortenbaugh. THE COST OF STEAM POWER. II. By Dr. Chas. E. Emery. PHASING TRANSFORMERS. By Chas. S. Bradley. REPORT OF PROF. R. A. FESSENDEN. No. 6 AND 7, JUNE AND JULY.

American Institute of Electrical Engineers.

Members of the Institute, who have been transferred from associate to full membership, can now receive the official Certificate issued by the Institute, upon applying to the Secretary, and enclosing the sum of two dollars ($2.00) to cover cost of same, and the engrossing of names, necessary dates, etc. In ordering a certificate, the name of the applicant should be plainly written, exactly as he desires to have it appear. These Certificates are printed upon heavy parchment paper, from an engraved steel plate.

Associate as well as Full Members are entitled to receive the Official Badge of the Institute, which is now prepared in the following forms and at prices stated: Pin, $3; Scarf-pin, $3; Lapel Button, $3; Watch Charm, $3; Locket for single picture, $8; Double Locket for two pictures, $10.

THE OFFICIAL BADGE ADOPTED BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS EMBODIES THE FOLLOWING CHARACTERISTICS.

FRANKLIN'S KITE, which demonstrated the identity between **Lightning** and **Electricity**, and represents **static electricity**. It is a recognition of **America's first Electrician** and **Philosopher, Benjamin Franklin.**

A diagrammatic representation of **Wheatstone's Bridge**, one of the most important pieces of electrical testing apparatus.

THE GALVANOMETER, another equally important piece of testing apparatus and which represents **Magnetism** and **Induction.**

THE AMBER of which the galvanometer is made represents the **first conception of electricity**, dating back to 600 years B. C., when Thales, the Greek philosopher, recorded the fact that amber, when rubbed, attracted light particles to it, and the Greeks worshipped it, believing the gods had endowed it with life, and that it possessed a soul.

In 1600 A. D., Dr. Gilbert, court physician to Queen Elizabeth, coined the word **Electricity** from the word **Elektron**, the Greek name for Amber.

A. I. E. E. represents the initials of the American Institute of Electrical Engineeers.

C=E/R represents represents Ohm's Law—a fundamental law in electrical work.

The badge is made of white enamel, with the lettering and front portions of 18 karat gold, and the backing in 14 karat gold. **Apply to the Secretary, 26 Cortlandt St., New York**